

GUIDELINES ON USE OF INDUSTRIAL WASTES FOR ROAD EMBANKMENT AND SUBGRADE CONSTRUCTION



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GUIDELINES ON USE OF INDUSTRIAL WASTES FOR ROAD EMBANKMENT AND SUBGRADE CONSTRUCTION

1. INTRODUCTION

India is undertaking large scale infrastructure development projects in the country through different programmes viz. National Highway Development Programme (NHDP); Pradhan Mantri Gram Sadak Yojana (PMGSY), Mukhya Mantri Gram Sadak Yojna (MMGSY), and other State-sponsored programmes. Considering the magnitude of the road infrastructure projects carried out in the country, there is a stress on natural resources and are depleting very fast. Restrictions on quarrying also have increased the lead distances, increasing significantly the total cost of road construction. The availability and need for suitable construction materials are very significant and account for about 30-40% of the total cost of construction. In this context, the cost of road projects currently planned can significantly come down, with the utilization of locally available waste material, also recognised as “Industrial By-Products” or IBP. Considering the low (even negligible) landed costs of such locally available waste materials, the highway planners could come up with more ambitious highway/road projects, significantly increasing the magnitude of length, coverage and connectivity.

The conventional road construction technology is primarily dependent on natural borrow soil and aggregates quarried from a rock. Typically, in developed urban and industrial areas, natural borrow sources are scarce, expensive, and/or inaccessible. The environmental degradation caused due to the use of topsoil for embankment and subgrade construction is very high. Quarrying of aggregates from rock deposits underlying overburden also results in loss of forest lands, noise, dust, vibrations and flying debris due to blasting, pollution hazards leading to environmental hazards. Hence there is an urgent need to find new alternative materials for road construction which would not only reduces the total cost of the project but also protect our environment and results in sustainable road construction. By using Industrial waste materials fruitfully for road construction, instead of causing any environmental damage at the source as in the case of natural materials, there would be an environmental advantage at the waste source, as they are readily picked up and used beneficially elsewhere.

There are several potential Industrial By-Product/waste materials in the country viz. pond ash, copper slag, zinc slag, Jarofix, steel blast furnace slag, phosphogypsum, red mud, marble dust, foundry sand, mine tailings, incinerated residue etc. for utilization in an embankment and different layers of road pavement. A review of the literature indicated that annual production of different Industrial waste materials in the country as; copper slag (6-6.5 Million Tonnes (MT)), zinc slag (0.1-0.2 MT), steel blast furnace slag (10-12 MT), pond ash (180-200 MT), red mud (8-10 MT), phosphogypsum (12-13 MT), jarosite (0.3-0.5 MT), and lime sludge (4-6 MT). These quantities may vary every year depending on the growth of our industries. Limited use of these materials has created a huge heap of waste dumps inside the plant premises/nearby areas, causing environmental pollution. Presently, the utilization of these wastes is much more crucial and concern in India due to their large amount of production with limited applications.

CSIR-Central Road Research Institute, New Delhi has carried out detailed R&D studies on several waste materials/IBPs; developed technical design specifications and has implemented the technologies in the field by construction of experimental test tracks along actual highways with the support of waste-producing industry and all stakeholders. The performance of these sections was monitored under actual traffic and environmental conditions over a while. The data were analysed and conclusions were drawn regarding their feasibility for large scale field applications.

However, there was a need to prepare a comprehensive document, for awareness, and guidance for all stakeholders on use of different waste materials in road construction. Accordingly, the task was assigned to the Embankment, Ground Improvement and Drainage Committee (H-4) of IRC during the tenure 2018-20. A subgroup consisting of Prof. G.V. Rao (Subgroup Chairman), Dr. Vasant G. Havanagi, Shri U.K. Guruvittal, Prof. J.T. Shahu, Ms. Minimol Korulla, Shri Shahrokh Bagli, Shri Saurabh Vyas, Shri Sudhir Mathur, Prof. Amit Prashant, Prof. M. Venkataraman was constituted to prepare the draft. Later, Dr. A.K. Sinha and Ms. G.S.Parvathi were also included in the subgroup. The draft prepared by the subgroup was discussed in various meetings of the H-4 Committee and was finalized in its meeting held on 09.09.2020.

The composition of H-4 Committee is given below:

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Director General (Road Development) & Special Secretary to Govt. of India	(Pandey, I.K.), Ministry of Road Transport & Highways
Secretary General, Indian Roads Congress	(Nirmal, Sanjay Kumar), Additional Director General, Ministry of Road Transport & Highways

The revised draft document was placed before the Highways Specifications and Standards Committee (HSS) in its meeting held on 12.09.2020 and continued on 19.09.2020 & 03.10.2020. The HSS Committee decided that the Convenor, H-4 Committee will modify the document based on written and verbal comments offered during the meeting and submit the final document to IRC for placing before the meetings of Executive Committee (EC) and Council. The EC in its meeting held on 18.02.2021 approved the draft document for placing before the Council. The 221st Mid-Term Council in its meeting held on 20th – 21st February, 2021 considered and approved the draft “Guidelines on Use of Industrial Wastes for Road Embankment and Subgrade Construction” for printing.

Based on the experience gained both at laboratory and field levels, these guidelines have been prepared keeping in view the available conventional specifications in MoRTH/IRC and MoRD. The guidelines with case histories bring awareness about the availability of different alternative local waste materials and would develop confidence among Highway and Rural Road construction authorities/departments for their effective implementation in the field.

1.1 Scope

These guidelines provide salient details regarding available alternative Industrial waste material resources, their typical engineering characteristics, design technical specifications, construction methodology and quality control tests. The guidelines are limited to the use of these materials for bulk utilization in road embankment and subgrade construction. However, the Indian Roads Congress (IRC) and Ministry of Road Transport & Highways (MoRTH) Specifications; Ministry of Rural Development (MoRD) Specifications for construction of earthen embankments/subgrade shall be broadly followed and applied for field construction.

1.2 Environmental Requirement

Considering the environmental safety, it is mandatory as per CPCB/MoEF&CC guidelines to evaluate the leachate characteristics of all the waste materials proposed to be used in road construction. Toxicity Characteristic Leaching Procedure (TCLP) is a soil sample extraction method used to evaluate the leachate characteristics following USEPA:1311/3050/3052 procedures. When a material is proposed to be used in embankment/subgrade/landfills, the leachate produced may pollute the underground water resources or may contaminate the air affecting the health of the society surrounding these dumps. The TCLP test determines the

quantity of hazardous substances especially, the presence of some chemicals and heavy metals in the waste material. If the levels of all these hazardous substances are below TCLP limits, the material can be safely disposed of in landfills/or utilized in road embankment/subgrade without any treatment. If the levels exceed the limits, these materials have to be utilized in road embankment and subgrade, only after further treatment by adopting neutralization or/and stabilization/any other remediation techniques. After, adopting any suitable remediation techniques, the limits of heavy metals and any other toxic substances shall be below the regulatory limits as specified in MoEF&CC (2016) and revised guidelines, if any. The material is then considered as a non-hazardous and safe material for its utilization in road construction. The remediation techniques shall be carried out at the source and the responsibility of the same lies with the waste-producing Industry. To authenticate the suitability of the adopted treatment technique, a certificate/TCLP test report may be obtained from the waste-producing Industry. An independent evaluation may also be carried out by authorities through reputed Institutions working under CSIR like the Indian Institute of Toxicology Research, Lucknow (CSIR-IITR) or National Environmental Engineering Research Institute, Nagpur (CSIR-NEERI) or any other reputed Government Institutes.

2. FLY ASH

2.1 Production and Utilization

Fly ash is a fine residue that results from the combustion of ground or powdered coal at temperatures in the range of 1300 to 1450°C. When pulverised coal is burnt in the furnace of the power stations, about 80 percent of the ash produced is very fine. This part gets carried along with flue gases and is collected by using either an electrostatic precipitator or cyclone precipitator. This is called fly ash. The remaining ash sinters and falls at the bottom of the furnace. This is known as bottom ash. Fly ash may be disposed of in dry form in ash mounds or through water slurry in a pond. When fly ash and bottom ash are mixed and disposed of in the form of water slurry into the ash ponds, it is called pond ash. For embankment construction, either pond ash, bottom ash or mound ash can be used. However, it may be noted that the term “Fly ash” is commonly used as a generic term to denote any type of coal ash. For these guidelines, the term fly ash would denote Pond Ash/Bottom Ash/Mound Ash, which are to be used for embankment construction.



Fig. 2.1 Location Map of Thermal Power Stations in India

The production of fly ash in India from both captive/NTPC and state-owned power stations is about 180-200 million tonnes at present and may continue to increase with the set up of more

thermal power stations in the country (**Fig. 2.1**).

The most important utilization area of fly ash include; cement manufacturing; manufacture of pavement blocks/tiles; Reclamation of the low lying area; Agriculture; Dyke construction and Road construction. The road sector contributes to about 5-10% of total fly ash Utilization. However, bulk utilization of fly ash is in road embankment construction. Fly ash was successfully utilized in some highway embankment projects in the country viz. Nizamuddin approach embankment, Delhi; Shastri park, Delhi; Signature bridge approach, Delhi; Noida-Greater Noida expressway, Uttar Pradesh; Varanasi Ring road, Uttar Pradesh; Nagpur Bypass, Maharashtra etc.

Fly ash was also successfully utilised as a backfill/reinforced fill in many flyover approaches especially in urban areas viz. Okhla flyover, Delhi; Sarita Vihar flyover, Delhi, Udaipur-Chittorgarh state highway, Rajasthan; Chennai outer ring road project, Tamil Nadu etc. Due to its low unit weight (lightweight material) with high frictional characteristics, fly ash is also a preferred material for the construction of embankments over weak subsoil. Fly ash was used on some sections along Dankuni-Kolhaghat National Highway (NH-6), West Bengal; Reinforced Earth Wall constructed on soft soil at Gangavaram Port, Visakapatnam; Reinforced Earth Wall construction at Korba, Chhattisgarh etc. Reinforced fly ash was also used as a basal mattress to prevent subsoil failures.

2.2 Environmental Concerns

Fly ash is causing environmental pollution, creating health hazards and requires large areas of precious land for disposal. The environmental degradation caused due to the use of topsoil for embankment construction is very high. Moreover, many power plants are situated in urban areas, and therefore, fly ash can provide an environmentally preferable alternative to natural borrow soil. Fly ash utilization in road embankment construction has been made mandatory by several MoEF&CC notifications circulated regularly. These notifications shall be strictly adhered to by all involved stakeholders.

2.3 Physical, Chemical and Geotechnical Characteristics of Fly Ash

The study of physical, chemical and engineering characteristics are essential before recommending fly ash for road embankment applications. The properties of fly ash vary depending upon the type of coal, its pulverisation and combustion techniques, their collection and disposal systems, etc. Ash collected from the same ash pond may exhibit different physical and engineering properties depending on point of collection, depth, etc. Ash from two different thermal power plants can be expected to have different properties. These factors can be easily taken care of during laboratory characterisation, design and quality control operations during construction. Despite variations in its properties, fly ash possesses several desirable characteristics, such as lightweight, ease of compaction, a faster rate of consolidation, etc. Also, the spreading and compaction of fly ash can be started much earlier in comparison to the soil after a rainfall.

2.3.1 Physical and Chemical Characteristics

Typical values for the Physical and Chemical properties of fly ash are given in **Table 2.1**. The

properties depend on the type of coal used; combustion temperature and process. These values may vary from different power stations and shall not be cited for approval or rejection. Specific gravity, Loss on ignition and specific surface area are typical physical characteristics that would indicate the type of fly ash used for embankment construction. The Specific gravity of fly ash varies in the range 1.9-2.55 indicating its lightweight as compared to conventional soil. This affects the compaction, shear strength and permeability characteristics of fly ash.

The chemical characteristics indicate that fly ash mainly consists of silica, alumina and iron oxide. If the CaO content <5%, it is called class 'F' fly ash, If the CaO content >5%, it is called class 'C' fly ash. The majority of power stations in the country are producing class F fly ash. Though there may be a presence of Pb, Cd, Cr, Cu, Zn, Fe, Mn and Ni in fly ash samples, several research studies have indicated that there is very little possibility of underground water pollution due to the leaching of these heavy metals. Also, as fly ash is used in the core of the embankment and with the pavement above, deep groundwater level, there is very little possibility of saturation and reaching of leachate into groundwater.

Table 2.1 Typical Physical and Chemical Characteristics of Fly Ash*

S.No.	Parameter	Value
1	Specific Gravity	1.90-2.55
2	LOI	0.5-7.2
3	Specific surface area	250 to 850 m ² /kg
4	SiO ₂ (%)	40-60
5	Al ₂ O ₃ (%)	14-33
6	Fe ₂ O ₃ (%)	2-17
7	CaO (Lime) (%)	1-24
8	MgO (%)	0-5
9	SO ₃ (%)	1-3

**Data given are indicative only and shall not be cited for approval or rejection*

2.3.2 Geotechnical Characteristics

To investigate the suitability of fly ash for road embankment applications, the study of Geotechnical characteristics viz. plasticity; compaction; shear strength; consolidation and permeability characteristics are essential. Typical geotechnical characteristics of fly ash are given in **Table 2.2**. The values indicate that fly ash has low Maximum Dry Density (MDD), good shear strength and low compressibility characteristics. These properties indicate their suitability for embankment construction. Fly ash with a low MDD value should not be rejected for using it as fill material. However, in general, fly ash having MDD lower than 1 gm/cc is not suitable for embankment construction. The variation in geotechnical properties depends on the quantity of coarser particles (bottom ash) or finer particles (fly ash).

The settlement and slope stability of road embankment depend on consolidation and shear strength characteristics respectively. Fly ash with its low compressibility characteristics shows negligible post-construction settlements. There is very little possibility of liquefaction to occur when fly ash is used in embankment construction, as the material is compacted to the maximum dry density at optimum moisture content, i.e., under partially saturated conditions. In regions of moderate to high seismic activity, analysis of embankment stability should consider the liquefaction potential of the ash fill. To avoid the possibility of any liquefaction occurring, the following precautions may be taken:

- Proper compaction of the fill material as per MoRTH/MoRD specifications
- In case the water table is high, it should be lowered by providing suitable drains or capillary cut-off

Table 2.2 Typical Geotechnical Properties of Fly Ash*

S.No.	Parameter	Range
1	Plasticity	Non-Plastic
2	Maximum Dry Density (gm/cc)	0.9 -1.6
3	Optimum Moisture Content (%)	38.0 - 18.0
4	Cohesion (kN/m ²)	Negligible
5	Angle of Internal Friction (ϕ)	30° - 40°
6	Coefficient of Consolidation C_v (cm ² /sec)	1.75×10^{-5} to 2.01×10^{-3}
7	Compression index C_c	0.05– 0.4
8	Permeability (cm/sec)	8×10^{-6} to 7×10^{-4}
9	Grain Size Distribution (% of materials)	
	Clay size fraction	1 -10
	Silt size fraction	8 - 85
	Sand size fraction	7 - 90
	Gravel size fraction	0 - 10

**Data given are indicative only and may vary depending on the type of coal, shall not be cited for approval or rejection*

2.4 Design Specifications and Application Potential

2.4.1 Road Embankment

Fly ash is a silt size material, its behaviour is similar to sand and has many advantages for its use in road embankment construction. Despite variations in its properties, fly ash possesses several desirable characteristics as compared to conventional soils, such as lightweight, ease of compaction, a faster rate of consolidation, good permeability etc. Fly ash gets consolidated at a faster rate and primary consolidation is completed very quickly. It has low compressibility and shows negligible post-construction settlements. Hence, the spreading and compaction of

fly ash can be started much earlier in comparison to the soil after rainfall. Fly ash has better shear strength characteristics (c and ϕ) as compared to conventional soil. Also, fly ash would be a preferred material for the construction of embankments over weak subsoil because of its lightweight.

One of the disadvantages of using fly ash in embankment construction is its erodibility nature. If fly ash embankment is constructed without any cover soil, either there will be dust pollution or on exposure to water during rainfall, the embankment would be completely eroded and results in failure of road pavement. Hence a suitable cover soil of good earth shall be provided on slopes of fly ash embankment. The specification of cover soil shall meet the plasticity, dry density and swelling criteria as specified in MoRD/MoRTH specifications for embankment construction.

2.4.2 Approaches to Fly Over

There is a huge requirement of good earth in the range of 3000 m³ to 4000 m³ for the construction of a flyover approach embankment both in urban and rural areas. Considering the number of advantages of fly ash (section 2.4.1), fly ash is a good alternative to conventional soil for both retained and reinforced fill in flyover approach construction. The use of fly ash as a reinforced/retained fill is not only economically beneficial but also helps to preserve the environment.

2.4.2.1 As Retained Fill Material

Apart from the suitability of fly ash for highway embankment, fly ash has also been successfully utilised in retained fill in many flyover approach embankments in the country. The minimum dry density and FSI (free swelling characteristics) requirements are the same as those specified for fly ash highway embankment. However, the recommended other geotechnical characteristics for its use as retained fill are (a) Angle of internal friction (ϕ°) > 25° and (b) Plasticity Index (PI) < 20. In general, all fly ashes in the country qualify these criteria.



Fig. 2.2 Utilization of Fly Ash as retained fill at Sarita Vihar Flyover, Delhi

2.4.2.2 As Reinforced Fill/Backfill Material

Fly ash, considering its various advantages (section 2.4.1) especially the good shear strength and permeability characteristics, makes it a better material for Reinforced fill/Backfill material.

Fly ash was successfully utilised as a backfill/reinforced fill material in several approaches of a flyover in the country viz. Okhla flyover, Delhi; Sarita Vihar flyover, Delhi (**Fig. 2.3**); Fly overs along Udaipur-Chittorgarh highway (**Fig. 2.4**); Chennai outer ring road project (**Fig. 2.5**).

Fly ash used for reinforced fill shall be clean, free-draining and shall have $PI < 6$ and $Cu > 2$. It is recommended to use fly ash having $MDD > 1 \text{ gm/cc}$ for reinforced fill to prevent the pullout failures of top layers. The minimum angle of friction of fly ash shall be 30° . Though the fly ash material does not meet the criteria of backfill/reinforced material (Passing 75 micron shall be less than 15% as per IRC:SP:102), the criteria need to be relaxed considering its high shear strength, good permeability characteristics and experience gained during the construction of some flyovers in the country. Flyover approach embankment studies have shown that there are improved pullout factors with fly ash-geosynthetic materials as compared to conventional soil. This reduces the number of layers of geosynthetic material economizing the cost of flyover construction. During the construction, every care should be taken by the contractor, for proper drainage of the reinforced fill portion and it shall be ensured that there is no movement of particles of fly ash through the joints in the facing panel. For design and other construction details IRC:SP:102 may be followed.



Fig. 2.3 Geotie Reinforced Fly Ash-Sarita Vihar Flyover, New Delhi

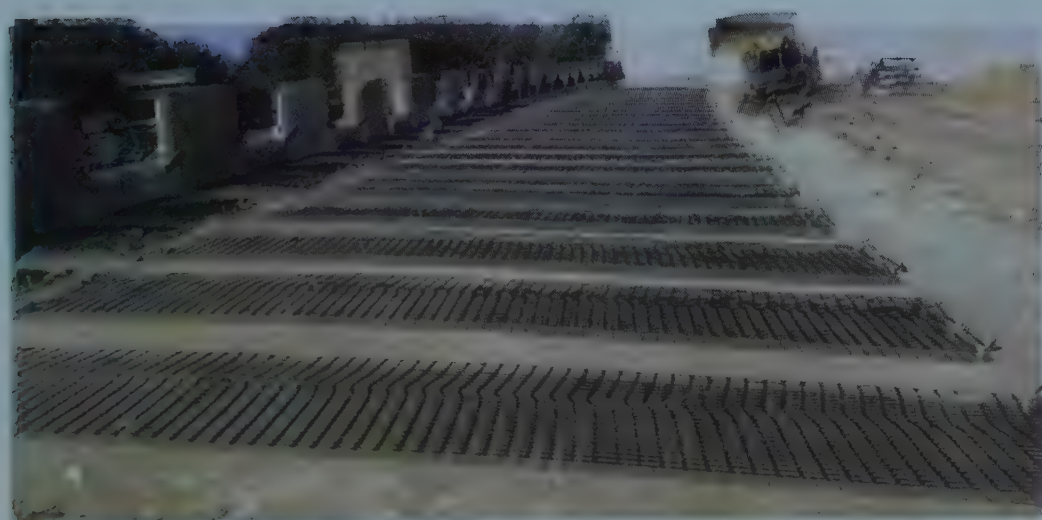


Fig. 2.4 Geogrid Reinforced Fly Ash-Udaipur-Chittorgarh National Highway (NH-76)



Fig. 2.5 Reinforced Fly Ash usage-Chennai Outer Ring Project

2.4.2.3 Reinforced Fly ash as Basal Mattress

Fly ash reinforced with geosynthetic materials viz. Woven geotextiles, Geogrids and Geocell can be used as a basal mattress below the embankments or Reinforced earth walls constructed over weak subsoils. Fly ash with its good permeability and high angle of internal friction becomes a suitable material for the basal mattress. The reinforcement may be laid in single or multi-layers as required. Its provision prevents differential settlements; bearing failures; and also provides resistance against lateral extrusion of foundation soil as well as slip failure of embankments. Apart from these benefits, Reinforced fly ash basal mattresses also act as drainage blankets below the embankment. Fly ash reinforced mattress shall be laid below the entire base width of the embankment or below the RE wall approach embankment. The thickness of the basal mattress depends on the drainage and design requirements and shall vary between 0.4 - 0.6 m.

The detailed design of the basal mattress of embankment shall be carried out as per IRC:113. Several projects have been completed by CSIR-Central Road Research Institute, New Delhi using Reinforced fly ash mattress at Okhla flyover, New Delhi and Dankuni to Kolhaghat, road embankment, West Bengal (**Fig. 2.6**). A typical cross-section of a Reinforced fly ash mattress is given in **Fig. 2.7**.



Fig. 2.6 Reinforced Fly Ash as Basal Mattress-Dankuni to Kolhaghat Highway, West Bengal

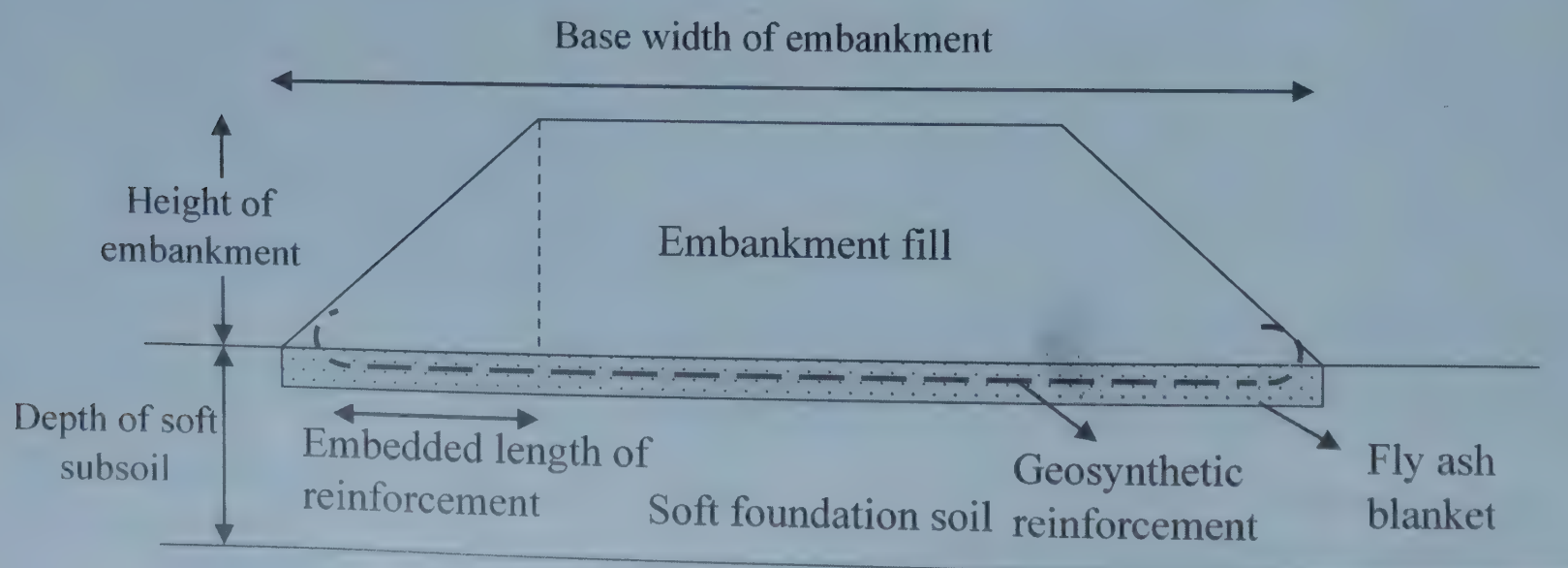


Fig. 2.7 Typical Cross-Section of Basal Mattress for Embankments over Soft Subsoil

2.5 Design Methodology and Typical Cross-Sections

Typical design cross-sections for both National Highway and Rural Road are shown in **Figs. 2.8 & 2.9**. Considering the erodibility characteristics of fly ash, a soil cover and an intermediate layer is proposed for its stability. For embankment up to 1 m height (In general in Rural Roads), the compacted cover thickness of 0.3 m-0.5 m (measured horizontally) shall be provided. For embankments greater than 1 m height, the compacted thickness of the side cover shall be increased to 1-2 m (measured horizontally) and shall be decided based on site conditions.

The same soil used for cover soil may be used as an intermediate layer. An intermediate layer of compacted thickness 150 mm (Rural Road)/200 mm (National Highway) is proposed after every 2 m rise in the height. This has been proposed for ease of construction and to provide adequate confinement for the fill material. This would also protect the fly ash material from erosion during possible rainfall during construction.

The specification of cover soil shall meet the plasticity, dry density and swelling criteria as specified in MoRD/MoRTH specifications for embankment construction. The side cover should be regarded as a part of the embankment for design analysis. The embankment would, therefore, be designed as a composite structure with fly ash in the core and earth cover on the sides. However the cross-sections for field implementation shall be finalized based on fly ash/soil characteristics, the field conditions seismic and loading conditions. The minimum factor of safety from the stability analysis shall not be less than 1.25. Settlement analysis shall also be carried out to meet the criteria as per IRC:SP:75. Further details for design methodology can be referred to in IRC:SP:58.

2.6 Construction Methodology

IRC:SP:58 shall be referred for detailed construction methodology of fly ash embankment. However brief methodology has been discussed below.

1. After clearing and grubbing, the ground shall be stripped to a depth of 150 mm, the soil of which may be used as cover soil. The stripped ground shall be compacted to achieve 95% of MDD determined as per IS:2720 (Part 8)-1983 (305.3.4cl. of MoRTH) or as per (301.5.4 cl. MoRD) before laying the first layer of fly ash embankment.

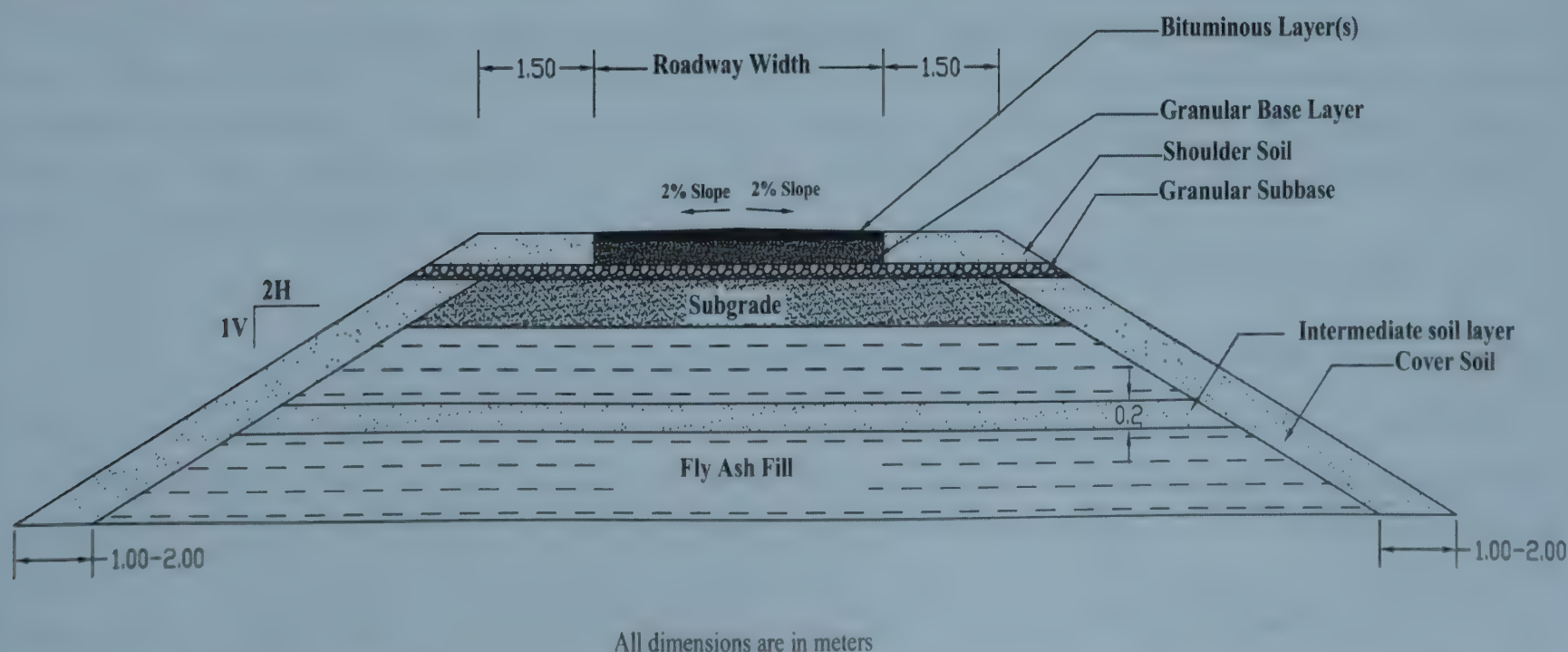


Fig. 2.8 Typical Cross-Section of Fly Ash Embankment for National Highway

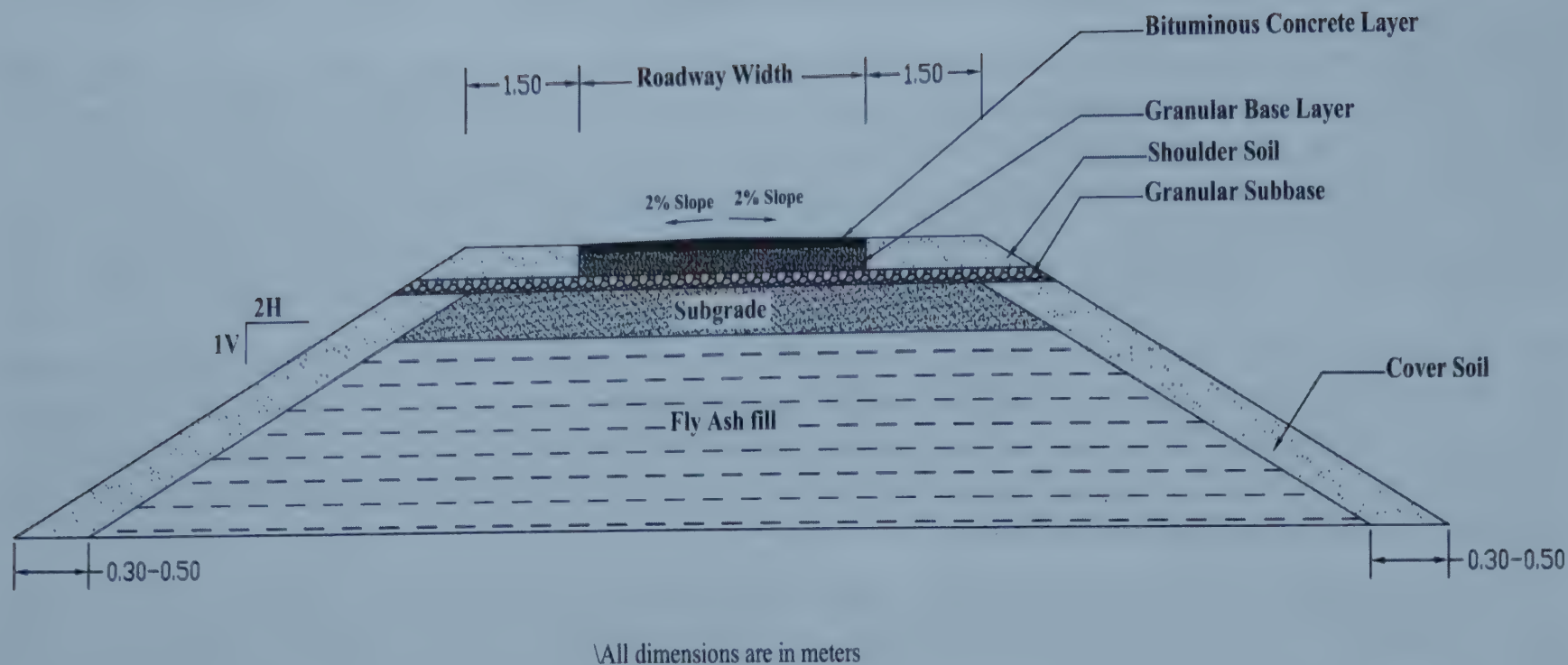


Fig. 2.9 Typical Cross-Section of Fly Ash Embankment for Rural Road

2. The side soil cover of the required width shall be provided along with the core and mechanically compacted as the embankment progresses upwards. The addition of side cover after the construction of the core is prohibited.
3. Moisture content of the fill material shall be checked at the site of placement before the commencement of compaction. The moisture content of fly ash laid for compaction shall normally vary from OMC (determined as per IS: 2720 (Part 8/7):1983) to $OMC \pm 2$ percent. Fly ash can be compacted using vibratory or static rollers.
4. Compaction/degree of compaction requirements for both National Highway (MoRTH) and Rural roads (MoRD) are given in **Annexure I**.
5. When fly ash is used in fly over's either in the retained fill or reinforced fill, compaction methodology is similar to that of fly ash embankments. However, in the case of reinforced fill, care shall be taken to compact the fly ash laid within a width of 1 m from the facing with a plate vibrator. This would reduce the lateral stresses on the facia and helps in maintaining the design inclination of the facia.

2.7 Quality Control Tests

2.7.1 Control Tests for Fly ash collected from a Pond

Fly ash may have to be collected from different locations within the pond or different ponds, as per the availability. Different quality control tests viz. Plasticity Index; dry density; moisture content; etc needs to be carried out in the borrow area as per MoRTH/MoRD specifications. These results help assess the suitability of material/quality assessment during field construction. Tests and their frequency for both National Highways and Rural roads are given in **Annexure I**.

2.7.2 Acceptance Criteria for Field Compaction

Field dry densities of compacted fly ash can be evaluated either by the core cutter or sand replacement method. The number of tests to be conducted and acceptance criteria for both National Highways and Rural Roads shall be as per MoRTH Specifications for Road and Bridge Works, Section 900 or MoRD Specifications, Section 1803.2.2. The same has been given in **Annexure I**.

3. COPPER SLAG

3.1 Production and Utilization

Copper slag is produced in India at a rate of about (6-6.5 million tons/year) and its total accumulation till date is more than 10 million tons. With limited usage, the excess waste material is dumped haphazardly on a costly land near the slag producing Industry. (**Fig. 3.1**).



Fig. 3.1 View of Copper Slag Mound at Tuticorin, Tamil Nadu

Copper slag is an industrial by-product material produced from the process of manufacturing copper. It is produced by

- (i) **Roasting**, in which Sulphur in the ore is eliminated as Sulphur dioxide (SO_2);
- (ii) **Smelting**, in which the roasted product is melted in a siliceous flux and the metal is reduced; and
- (iii) **Converting**, where the melt is desulphurized with lime flux, iron ore, or a basic slag and then oxygen lanced to remove other impurities.

The general process diagram of the smelting of copper concentrates in a reverberatory furnace is shown in **Fig. 3.2**.

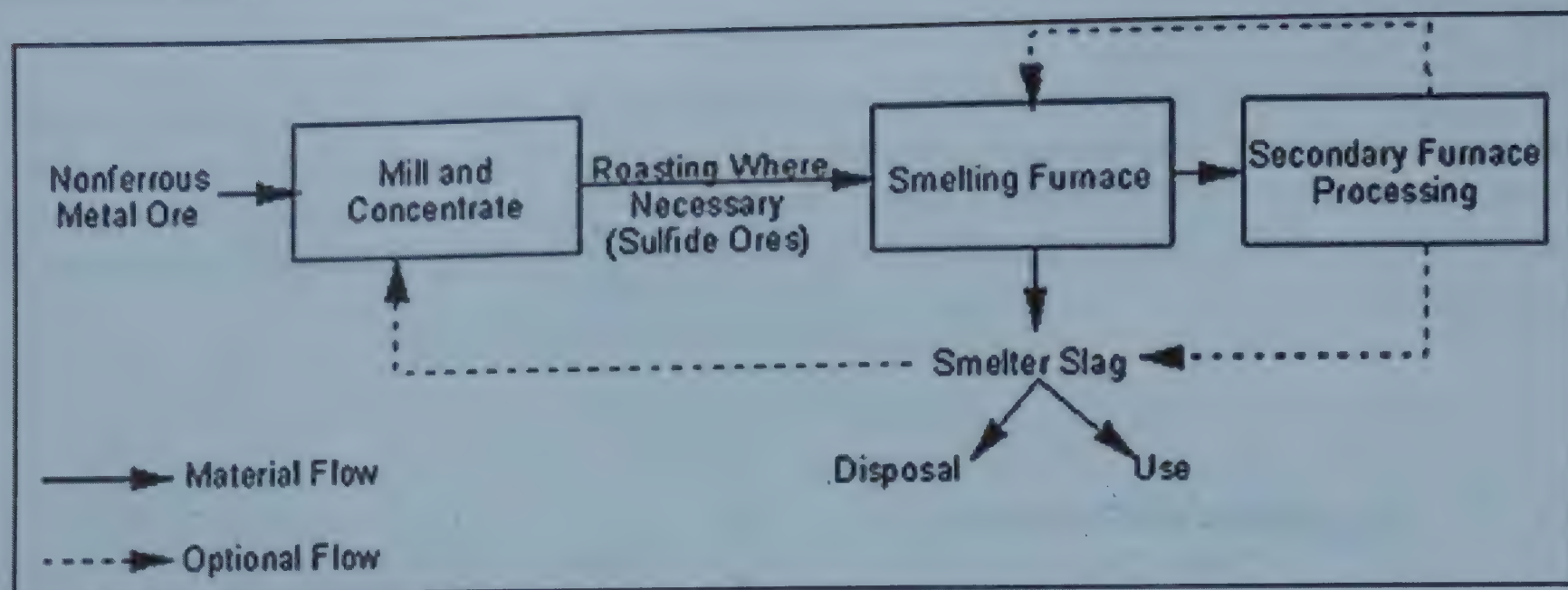


Fig. 3.2 General Process Diagram of Copper Slag Production

There are two types of copper slag produced in the Industry viz. Fine and coarse types depending on the process of smelting adopted. At present, these types of copper slag are being used for shot blasting, additive for cement manufacturing, landfilling etc. These applications utilize only about 10% to 20% and the remaining quantity is dumped as waste material. Detailed laboratory investigations were carried by CSIR–Central Road Research Institute on coarse copper slags collected from copper Industries, located at Dahej (Gujarat) and Tuticorin (Tamil Nadu). The physical, chemical, geotechnical and other engineering characteristics were studied before coming to conclusions regarding its feasibility for use in embankment and pavement layers in road construction. An experimental Road embankment was constructed using coarse copper slag collected from an industry along NH-45 B (Madurai to Tuticorin). The performance of the same was monitored for two years (Details, **Annexure V**). Based on the experience gained at the laboratory and field level, these guidelines have been prepared for the benefit of the Rural Road/National Highway construction authorities/departments.

3.2 Physical and Chemical Characterisation of Copper Slag

Copper slag (coarse and fine) is a blackish material, similar to coarse sand/fine sand (**Fig. 3.3**). Typical physical properties and chemical composition of copper slag are summarised in **Table 3.1**.



Fig. 3.3 Close View of Fine and Coarse Copper Slag

Table 3.1 Typical Physical Properties and Chemical Composition of Copper Slag*

Property/Elements	Value
Specific gravity	3.2-3.6
Loss on ignition	Nil
Fe ₂ O ₃ (%)	40-45
Al ₂ O ₃ (%)	3-5
SiO ₂ (%)	28-35
SO ₂ (%)	0.5-1.5
CaO (%)	2-5
MgO (%)	1-3
CuO (%)	0.4-0.5

**Data given are indicative only and may vary depending on the source of copper ore*

3.3 Geotechnical Characteristics of Copper Slag

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. grain size analysis, standard proctor compaction tests, direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of both fine and coarse copper slag have been summarized in **Table 3.2**

Table 3.2 Typical Geotechnical Characteristics of different types of Copper Slag*

Property	Coarse Copper Slag	Fine Copper Slag
Grain size analysis		
Gravel (%)	0-2	0
Sand (%)	98-100	25-65
Silt (%)	0	28-70
Clay (%)	0	5-7
Atterberg limit test (PI)	NP	NP
MDD (kN/m ³) (IS:2720 (Part 8)-1983)**	21-24.5	19-22
OMC (%)**	7-11	11-17
Direct shear test (saturated)		
c (kN/m ²)	0	0
φ (degree)	35-39	20-36
Permeability (m/sec)	1.7x10 ⁻⁴	1.9x10 ⁻⁶
CBR (%)	35-50	14-21

** Data given are indicative only and may vary depending on the source of copper ore*

*** For Rural Road, IS:2720 (Part 7) shall be followed, the values may vary.*

3.4 Design Specifications and Application Potential

3.4.1 Road Embankment

Geotechnical characteristics of copper slag viz. high value of Maximum Dry Density (MDD); high frictional characteristics; high permeability characteristics indicated its suitability for road embankment construction. However, the construction of road embankment using 100% copper slag alone would not be feasible as these materials are cohesionless. Mechanical stabilization techniques i.e. mixing with soil/fly ash or other local materials shall be adopted to make it practically feasible for the construction of road embankments. However, the mechanically stabilized copper slag shall meet the specification criteria as per MoRTH/MoRD. Different methods of mechanical stabilization which may be adopted in the field are given below;

3.4.1.1 Mixing of Copper Slag with Fly ash/Other Wastes/Local Soils

The feasibility of mixing copper slag (fine/coarse) in different proportions with fly ash/other wastes/local soils needs to be studied in the laboratory. Copper slag can be mixed in general in the range of 10-75%. The optimum proportion of mixing shall be arrived at based on laboratory studies and satisfying the plasticity, swelling and dry density criteria as per MoRD (Section 301) and MoRTH (Section 305) specifications as required.

3.4.1.2 Mixing of Fine and Coarse Copper Slag

Depending on the availability of both fine and coarse copper slag in a particular industry, both can be mixed in different proportions for its improvement in gradation, dry density, shear strength and CBR characteristics. Detailed laboratory characterization needs to be carried out for optimizing the mix. The optimum proportion of mixing shall be arrived at based on laboratory studies and satisfying the plasticity, swelling and dry density criteria as per MoRD (Section 301) and MoRTH (Section 305) specifications as required.

Table 3.3 summarizes some of the typical geotechnical characteristics of copper slag (fine/coarse)-soil and copper slag (fine/coarse)-fly ash mixes, coarse+fine copper slag mixes. The plasticity, compaction, shear strength and permeability characteristics indicated their suitability in embankment construction.

Table 3.3 Typical Geotechnical Characteristics* of Copper Slag-Soil/Fly Ash Mixes, Copper Slag (Coarse+Fine)

Property	Copper Slag + Soil	Copper Slag + Fly ash	Copper Slag (Fine + Coarse)
Atterberg limit test (PI)	NP-14	NP	NP
MDD (kN/m ³), (IS:2720 (Part 8)-1983)**	20-25	15-24	22-25
OMC (%)**	6-13	7-30	5-12
Direct shear test (saturated)			
c (kN/m ²)	10	0	0

ϕ (degree)	30-34	25-37	30-38
Permeability (m/sec)	2×10^{-6}	7×10^{-6}	1.2×10^{-6}
CBR (%)	10-80	8-65	22-65

*Data given are indicative only, may vary depending on the type of Slag/local soil/Fly ash

** For Rural road, IS:2720 (Part 7) shall be followed, the values may vary.

3.4.1.3 Earth Cover and Intermediate Layers for Protection of Slopes

Intermediate soil and cover soil layers have to be used only when low plastic mechanically stabilized copper slag-fly ash/soil mixes ($PI < 10$) are used for embankment construction. Earth cover is needed to prevent erosion of copper slag-soil/fly ash stabilized layer. For embankment up to 1 m height (In general in Rural Roads), the compacted cover thickness of 0.3 m-0.5 m (measured horizontally) shall be provided. For embankments greater than 1 m height, the compacted thickness of the side cover shall be increased to 1-2 m (measured horizontally) and shall be decided based on site conditions.

The same soil which was used for mixing/cover soil may be used as an intermediate layer. An intermediate layer of compacted thickness 150/200 mm is proposed after every 2 m rise in the height embankment considering the practical feasibility. This has been proposed for ease of construction and to provide adequate confinement for the fill material. This would also protect the copper slag-fly ash material from erosion during possible rainfall during construction. In case of copper slag-soil mixes with $PI > 10$, though soil cover may not be needed, erosion control measures shall be taken up with Turfing/Seeding mulching techniques as discussed in section 307 and section 308 of MoRTH specifications.

The specification of cover soil shall meet the plasticity, dry density and swelling criteria as specified in MoRD/MoRTH for embankment construction.

3.5 Design Methodology and Typical Cross-Sections

3.5.1 Site Investigation

The site on which copper slag embankment is constructed should be investigated for its in-situ characteristics at least for a depth of 2 times the height of copper slag embankment. Apart from in-situ characteristics, hydrological data may also be collected which would be very useful for drainage design and evaluation of slope stability of copper slag embankment.

3.5.2 Slope Stability and Settlement Analysis

Stability analysis needs to be carried out by limit equilibrium methods as per IRC:75. Circular failure can be assumed in the analysis. The subsoil characteristics, fill characteristics, and traffic loading conditions need to be considered in the design. The analysis has to be carried out under different moisture conditions and considering the seismic factors. The factor of safety along a critical circle needs to be determined to evaluate the safety of the copper slag embankment. The factor of safety shall be more than 1.25. Settlement analysis shall also be carried out for the design section and shall meet the criteria as per IRC:75.

3.5.3 Suitability of Copper Slag as a Subgrade/Shoulder/Drainage Material

Copper slag can also be used in subgrade/shoulder and as a drainage layer. The Non-plastic/low plasticity ($NP/PI < 20$), High dry density ($MDD > 16.5 \text{ kN/m}^3$) and High CBR characteristics of copper slag-soil, copper slag-fly ash and mixes of fine and coarse copper slag (**Table 3.2**) indicated their suitability for construction of subgrade and shoulder. However, these mixes shall be confined with good earth (as discussed in section 3.4.1.3) to prevent possible erosion during the monsoon. When copper slag-soil mix is used as an embankment material, the same shall form the subgrade material. Black cotton soil and other expansive soils shall be used in subgrade construction judiciously considering the swelling characteristics of such soils. However, when copper slag-fly ash is used as an embankment fill material, a separate subgrade of thickness 300/500 mm of good earth/copper slag+soil shall be laid. In general, the physical and other requirements of embankment fill material; subgrade shall meet the criteria as per MoRD/MoRTH specifications.

Typical cross-sections of copper slag embankment for use in National Highways and Rural Roads are given in **Figs. 3.4** and **3.5**. The cross-sections only indicate the only mode of possible applications in different layers of road pavement. Actual cross sections for both National Highway and Rural road shall be arrived at based on embankment/pavement design procedures/principles given in IRC:75; IRC:37 and IRC:SP:72 respectively.

3.6 Construction Methodology

The construction methodology of the copper slag embankment has been briefly explained below.

Initially clearing and grubbing, setting out and dewatering of foundation of embankment shall be carried out as per prevalent MoRTH/MoRD specifications. The ground shall then be stripped to a depth of 150 mm, the soil of which may be used as cover soil. The stripped ground shall be compacted to achieve 95% of MDD determined as per IS:2720 (Part 8)-1983 (305.3.4cl. of MoRTH) or shall be compacted as per (301.5.4 cl.MoRD) before laying the first layer of copper slag-fly ash/soil embankment. If fly ash is used for mixing, it shall be dried in the sun till the ash becomes suitable for mixing. The totally dry Fly ash may be conditioned with 1-2% moisture before laying and mixing to avoid air pollution and dust nuisance.

An appropriate methodology of mixing may be adopted in the nearby site as discussed below;

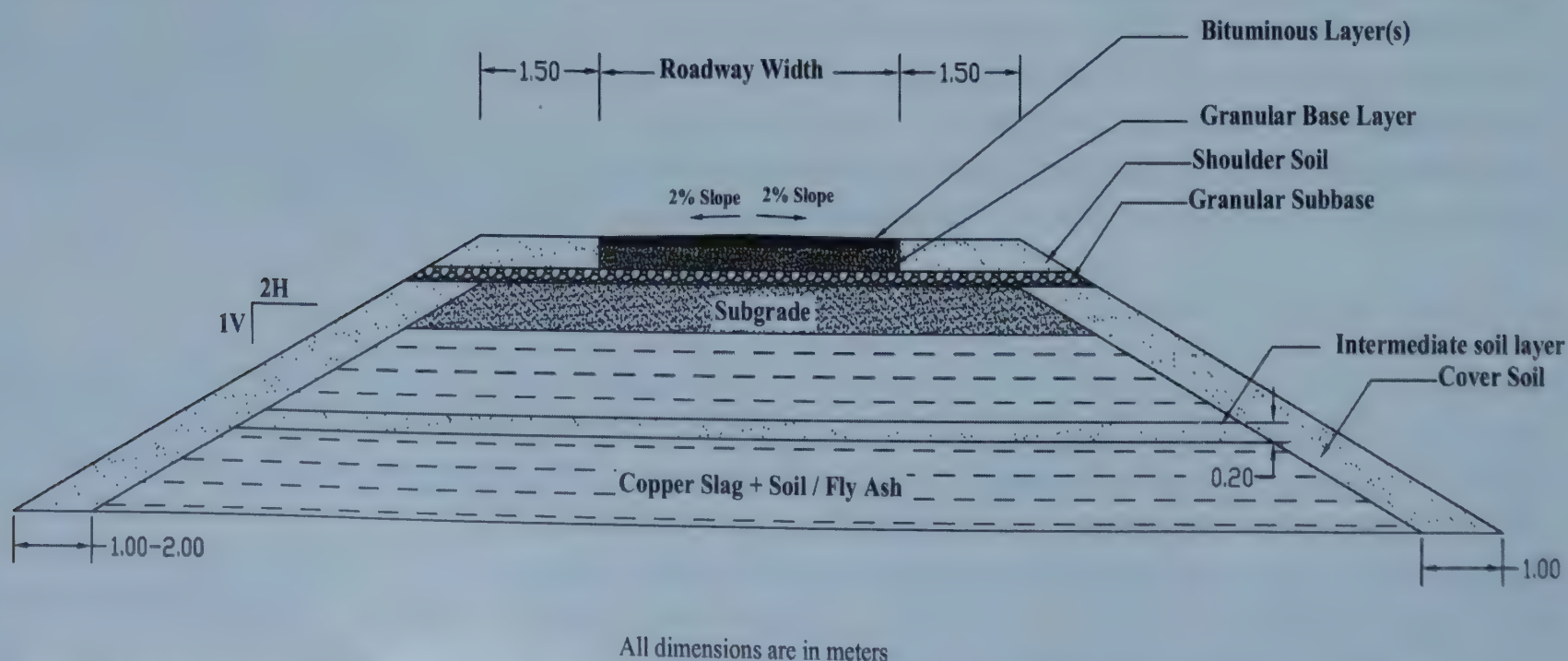
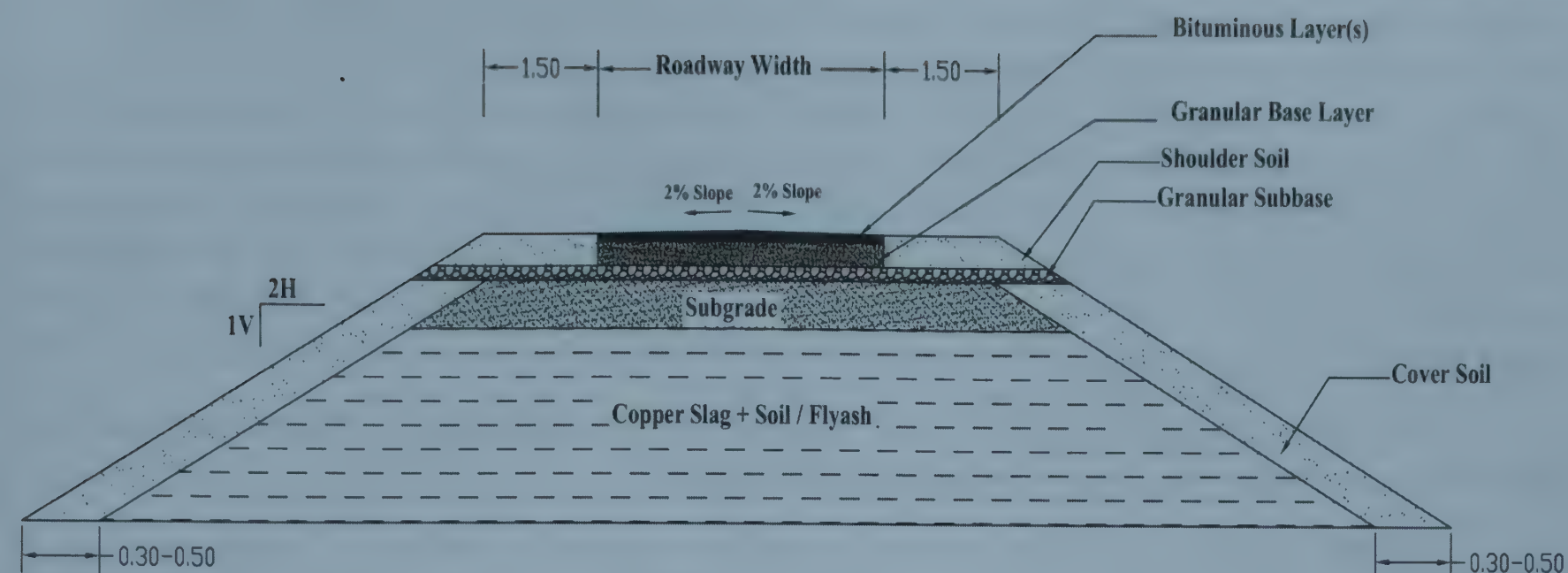


Fig. 3.4 Typical Cross-Section of Copper Slag Embankment for National Highway



All dimensions are in meters

Fig. 3.5 Typical Cross-Section of Copper Slag Embankment for Rural Road

(a) Mixing near the site by Dozers/Rotavator: Mixing of copper slag and fly ash/soil shall be carried out on weight (converted to volume as required) depending on the proportion arrived in the laboratory. A stack (cu.m) of fly ash/soil shall be laid in a large spread area and copper slag (cu.m) is then laid over it. Dozers/Rotavator may be used for thorough mixing. It should be noted that no pockets of unmixed copper slag/fly ash/soil shall be visible in the entire volume. The average compaction characteristics of this mix shall be evaluated in the laboratory and the value should be used for quality assessment in the field. The mixed sample is then laid in the field and with the addition of moisture ($OMC \pm 2$ per cent), this can be compacted as per conventional equipment/procedures as per MoRTH/MoRD specifications.

(b) Plant Mix Stabilization: Pug mill system/WMM plant can be used for mixing of copper slag with fly ash/soil as per the required designed proportions. The plant mixing ensures uniform homogenous mixing of the materials as per requirement. The wet mix (after the addition of moisture at $OMC \pm 2$ per cent) can then be transported to the place of construction/spread and compacted by conventional equipment/procedures.

(c) In-situ mixing: After preparation of the ground supporting the embankment, conditioned fly ash/dry soil shall be spread using dozers/graders to the required loose thickness. The copper slag is then spread over the same to the required loose thickness. The loose thicknesses of each of the fill materials have to be determined for the specified proportion (by weight) and for achieving a compacted thickness of 150/200 mm (as per MoRD/MoRTH) as required. The side soil cover of specified width (as per drawing) and loose thickness shall be spread along with the copper slag-soil/fly ash fill material (the core of the embankment). The addition of side earth cover after the construction of the core is prohibited. The loose layers of copper slag and soil/Fly ash are then dry mixed using a tractor towed tiller or Rotavator till a uniform mix is achieved. 2-3 passes of tiller in either direction (perpendicular) may be sufficient to achieve uniform mixing. The required amount of water is then added as per the Optimum Moisture Content (OMC) obtained from the Standard/Modified Proctor compaction tests. Water shall be sprinkled from a water tanker fitted with a sprinkler capable of applying water uniformly without any flooding. The moisture

content may vary within the range of +1% and -2% of OMC. Wet mixing is then carried out using the same equipment. The number of passes shall be the same as in dry mixing. However, the number of passes for both dry and wet mixing shall be determined by an experimental field study or as per the decision of the site engineer. The wet mix material shall then be spread by mechanical means, finished by the motor grader. Compaction shall be carried out preferably by vibratory rollers of dead weights of 8 to 10 tons to achieve a compacted thickness of 150/200mm as required. The cover soil has to be simultaneously compacted along with fill material as the embankment progress upwards. This would provide confinement to copper slag/soil/Fly ash mix.

1. The method of mixing (a, b, c) may be decided by the Engineer in charge depending on technical requirements and economical considerations.
2. Moisture content of the fill material shall be checked at the site of placement before the commencement of compaction. The moisture content of copper slag-fly ash/soil laid for compaction shall normally vary from OMC (determined as per IS: 2720 (Part 8):1983 to OMC ± 2 per cent. The layer can be compacted using vibratory or static rollers as explained in section 1(c).
3. Compaction/degree of compaction requirements for both National Highway (MoRTH) and Rural Roads (MoRD) are given in **Annexure I**.

3.7 Quality Control Tests

3.7.1 Control Tests for Copper Slag/Fly ash/Soil and their Mixes

The individual materials (copper slag/fly ash/soil) from the borrow areas shall be checked for dry density; in situ-moisture content etc as per BIS specifications. Tests and their frequency for both National Highways and Rural Roads are given in **Annexure I**.

3.7.2 Acceptance Criteria for Field Compaction

Field dry densities of compacted copper slag/fly ash/soil mixes can be evaluated either by core cutter or sand replacement method. The number of tests to be conducted and acceptance criteria for both National Highways and Rural Roads shall be as per MoRTH Specifications for Road and Bridge Works, Section 900 or MoRD specifications, section 1803.2.2. The same has been given in **Annexure I**.

4. JAROFIX

4.1 Production and Utilization

Jarosite is a waste material produced during the extraction of zinc ore concentrate by hydrometallurgy operation (**Fig. 4.1**). In the zinc concentrate, the zinc content available is more than 50%. This concentrate is roasted at 900°C and subjected to leaching where jarosite is formed as waste material. The jarosite is then mixed with 2 % lime and 10 % cement through a series of screw conveyor fitted mixing systems and transported to the disposal area with the help of a payloador and dumper. This waste material after mixing is termed Jarofix.

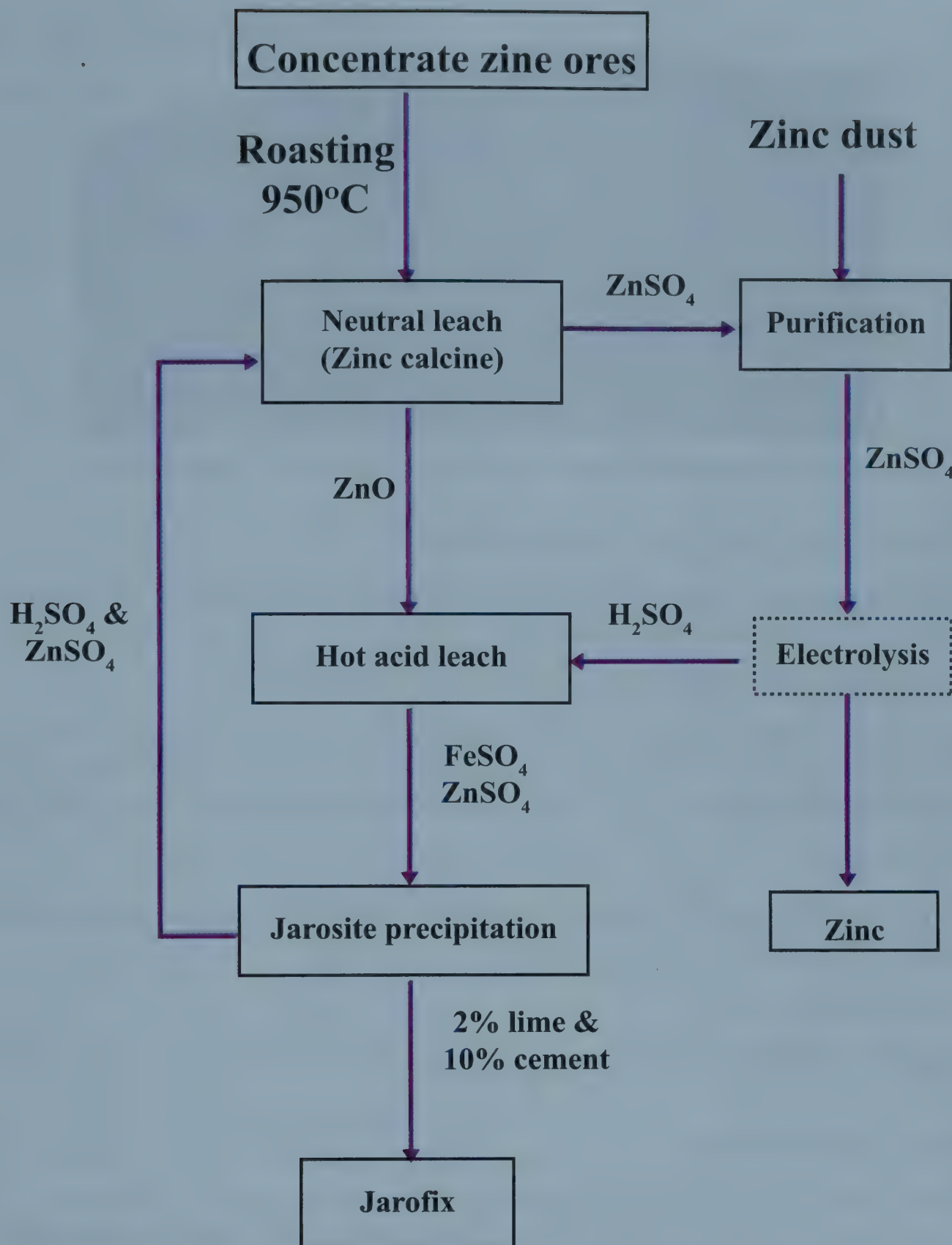


Fig. 4.1 Hydrometallurgical Process of Production of Jarofix

At present, the accumulated Jarofix is about 10 lakh tons, while the annual production in the country is about 3.4 lakh tons. Presently, it has no applications and is dumped on the costly land available near the plant (**Fig. 4.2**). CSIR-Central Road Research Institute, New Delhi carried out R&D studies to investigate the potential of Jarofix waste material collected from Chittorgarh, Rajasthan by detailed laboratory investigations and it was concluded that Jarofix waste can be suitably utilized in place of conventional soil for embankment and subgrade construction. An experimental test track using Jarofix was also constructed along Chittorgarh-Udaipur road (SH-9), where two lanes were widened to a four-lane divided highway. The results of performance observations for 2 years indicated its suitability in embankment and subgrade construction. Several other R&D studies in the country also indicated the potential of Jarofix in road construction.



Fig. 4.2 Jarofix Waste Dump, Chittorgarh, Rajasthan

4.2 Physical and Chemical Characteristics

Jarofix is yellowish and is a fine-grained material. Some of the typical physical and chemical characteristics have been discussed below;

4.2.1 Natural Moisture Content

The natural moisture content in the Jarofix material varies in the range of 30 to 37 %. The high natural moisture content is due to the generation of Jarofix in slurry form (hydrometallurgy operation) and due to the presence of a high percentage of finer particles (**Table 4.2**).

4.2.2 Specific Gravity

The value of the specific gravity of Jarofix ranges between 2.30-2.4, indicating that the Jarofix waste material is lighter than conventional soils.

4.2.3 Loss on Ignition

The loss on ignition value of Jarofix ranges between 7-8 % indicating a low amount of carbon content.

4.2.4 Chemical Characteristics

Typical chemical characteristics of Jarofix waste material are given in **Table 4.1**. It consists of a significant amount of Sulphates (SO_3); Iron Oxide (FeO) and Silica Oxide (SiO_2) with traces of heavy metals viz. Zn, Pb, Cd, Ni, Co, and Mn. the quantity of which should be less than the regulatory limits specified in MoEF&CC (2016 and revised guidelines, if any) before its application in the field.

Table 4.1 Chemical Properties of Jarofix*

Chemical Composition	Range (%)
SO_3	19-31
MgO	1-4
Al_2O_3	2-12
FeO	35-50
SiO_2	12-35
CaO	4-18

**Data given are indicative only and may vary depending on the source*

4.3 Geotechnical Characteristics

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of Jarofix have been summarized in **Table 4.2**.

Table 4.2 Typical Geotechnical Characteristics of Jarofix*

S.No.	Properties	Jarofix
1	Grain Size Analysis	Gravel = 2-5 % Sand = 2-20 % Silt = 65-85 % Clay = 10-12 %
2	Plasticity Index	PI = 7-17 %
3	Free Swelling Index Test (FSI)	10-12
4	Specific Gravity Test	2.3-2.40
5	Proctor Compaction Test ((IS:2720 (Part 8)-1983)**)	MDD = 11-16 kN/m ³ OMC = 48-22 %
6	CBR Test	6-7.5 %
7	Direct Shear Test	c = 5-14 kN/m ² ϕ = 22-27°

*Data given are indicative only and may vary depending on the source

** For Rural road, IS:2720 (Part 7) shall be followed, the values may vary

4.4 Design Specifications and Application Potential

4.4.1 Road Embankment

The typical geotechnical characteristics of Jarofix material viz. plasticity characteristics, dry density and free swelling characteristics indicate that the material satisfied both the MoRTH and MoRD criteria for use as an embankment material. Sometimes, due to variation in the lime content (during neutralization/stabilization of Jarosite), the specific gravity/Maximum Dry Density (MDD) may be slightly lower than as required as per MoRTH and MoRD. However, field performance studies have shown its feasibility for embankment applications. There is no need to add additional moisture before field compaction because of the presence of a high amount of in-situ moisture content. If the moisture content is above OMC, it shall be dried in the natural sun to achieve the OMC requirement before compaction.

A typical cross-section of Jarofix embankment is shown in **Fig. 4.3**. However, erosion control measures shall be taken up with Turfing/Seeding mulching techniques as discussed in section 307 and section 308 of MoRTH specifications. The vegetation of identified saplings can also be grown on slopes as shown in **Fig. 4.4**

4.4.2 Road Subgrade

The Maximum Dry Density (MDD) of Jarofix does not meet the MoRTH and MoRD minimum criteria for use in the subgrade layer of road pavement. Jarofix can be mechanically stabilized with local soil or other waste/local materials in the designed suitable proportion to achieve the specification requirement.

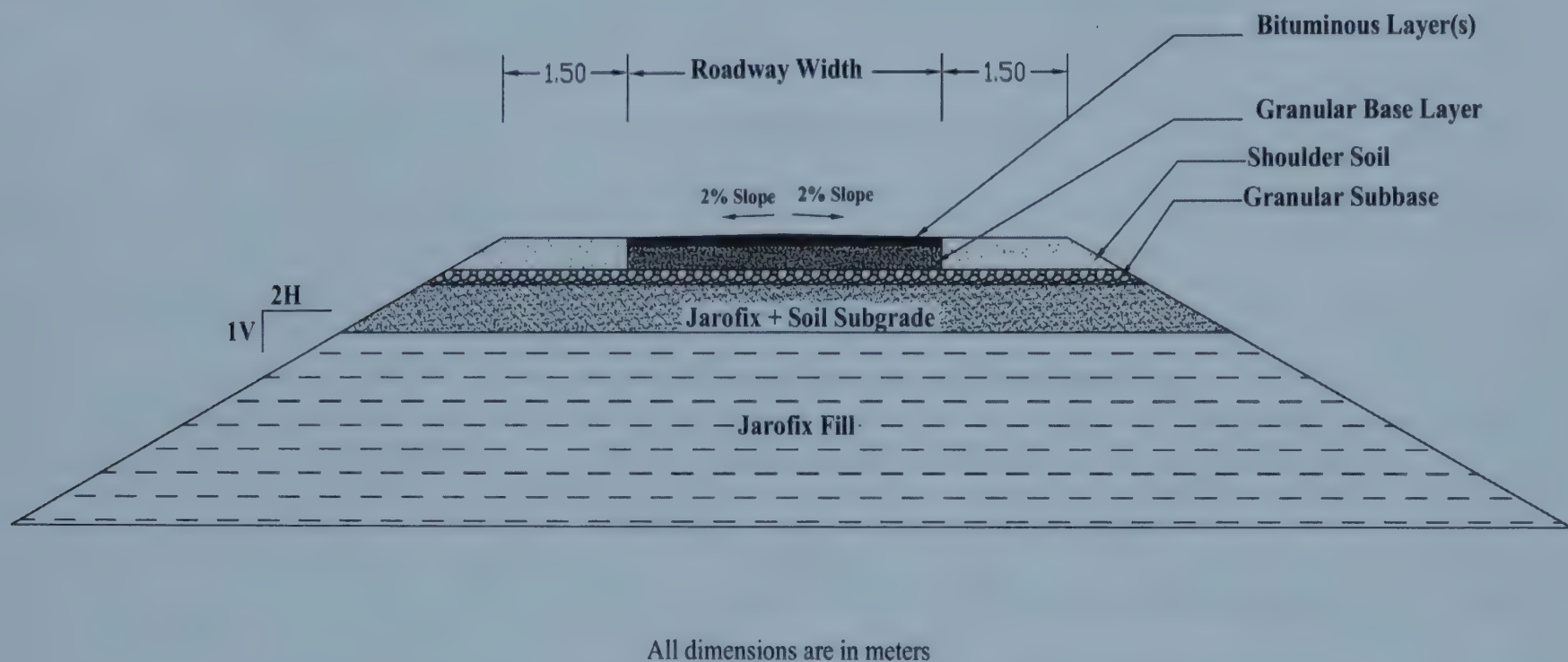


Fig. 4.3 Typical Cross Section for Jarofix Embankment (National Highway and Rural Roads)



Fig. 4.4 View of Vegetation Growth on the Slope of Jarofix

4.4.3 *Approaches to Fly over*

4.4.3.1 *As Retained Fill Material*

Apart from the suitability of Jarofix for highway embankment, Jarofix+Zinc slag mix (zinc slag available in the same industry, mix optimized in the laboratory) has also been successfully utilised as a retained fill in many flyover approach embankments along Udaipur-Chittorgarh four to six-lane highway project. The mixing was carried out considering the Maximum Dry Density criteria (MDD) and other requirements as per MoRTH specifications. However, based on its performance observations for highway embankment, it is recommended that 100% Jarofix without mixing can be used successfully for the construction of retained fill of flyover approaches.

4.4.3.2 *Design Methodology and Typical Cross-Sections*

Jarofix embankment can be designed similar to that adopted for conventional soil embankment. Typical design cross-sections for both National Highway and Rural Road can be arrived at after detailed stability and settlement analysis. Stability analysis needs to be carried out by limit equilibrium method as per IRC:75. Circular failure can be assumed in the analysis. The subsoil characteristics, fill characteristics, and traffic loading conditions need to be considered in the design. The analysis has to be carried out under different moisture conditions and considering the relevant seismic factors. The factor of safety along a critical circle of Jarofix embankment needs to be evaluated. The minimum factor of safety shall be more than 1.25. Settlement analysis shall also be carried out for the design section and shall meet the criteria as per IRC:75.

4.5 **Construction Methodology**

Construction of Jarofix embankment/subgrade/retained fill can be carried out using conventional methods and equipment as per section 305.3 of MoRTH/301.5 of MoRD specifications. The brief methodology of construction has been discussed below;

1. Initially clearing and grubbing, setting out and dewatering of foundation of embankment shall be carried out as per prevalent MoRTH/MoRD specifications. The ground shall then be stripped to a depth of 150 mm, the soil of which may be used as cover soil. The stripped ground shall be compacted to achieve 95% of MDD determined as per IS:2720 (Part 8)-1983 (305.3.4cl. of MoRTH) or shall be compacted as per (301.5.4 cl.MoRD) before laying the first layer of Jarofix embankment.
2. The moisture content of the Jarofix material shall be checked at the site of placement before the commencement of compaction. The moisture content of Jarofix laid for compaction shall normally vary from OMC to $OMC \pm 2$ per cent (determined as per IS:2720 (Part 7/ Part 8:1983). The layer can be compacted using vibratory or static rollers as found feasible to achieve the degree of compaction (**Annexure I**).
3. In case of Utilization of Jarofix for subgrade construction, as discussed earlier Jarofix has to be mixed with local soil or waste/marginal materials (as per availability) to meet the Maximum Dry Density (MDD) criteria as per MoRD/MoRTH specifications.

An appropriate methodology of mixing may be adopted in the nearby site as discussed below.

(a) Mixing near the site by Dozers/Rotavator: Mixing of Jarofix with zinc slag/soil/local material shall be carried out on weight (converted to volume as required) depending on the proportion arrived in the laboratory. A stack (cu.m) of Jarofix shall be laid in a large spread area and soil/zinc slag/local material (cu.m) is then laid over it. Dozers/Rotavator may be used for thorough mixing. It should be noted that no pockets of unmixed zinc slag/soil/local material shall be visible in the entire volume. The average compaction characteristics of this mix shall be evaluated in the laboratory and this value should be used for quality assessment in the field. The mixed sample is then laid in the field and with the addition of moisture ($OMC \pm 2$ per cent), this can be compacted as per conventional equipment/procedures as per MoRTH/MoRD specifications.

(b) Plant mix stabilization: Pug mill system/WMM plant can be used for mixing of Jarofix with zinc slag/soil as per the required designed proportions. The plant mixing ensures uniform homogenous mixing of the materials as per requirement. The wet mix (Moisture at $OMC \pm 2$ per cent) can then be transported to the place of construction/spread and compacted by conventional equipment/procedures.

(c) In-situ mixing: After preparation of the ground supporting the embankment, Jarofix shall be spread using dozers/graders to the required loose thickness. The zinc slag/soil/local material shall then be spread over the same to the required loose thickness. The loose thicknesses of each of the fill materials have to be determined for the specified design proportion (by weight) and a compacted thickness of 150/200 mm (as per MoRD/MoRTH) as required. The loose layers of Jarofix and overlying materials are then dry mixed using a tractor towed harrows or Rotavator till a uniform mix is achieved. 3-4 passes of harrow in either direction (perpendicular) may be sufficient to achieve the uniform mixing. The required amount of water is then added as per the Optimum Moisture Content (OMC) obtained from the Standard/Modified Proctor compaction tests (as required). Water shall be sprinkled from a water tanker fitted with a sprinkler capable of applying water uniformly without any flooding. The moisture content may vary within the range of +1% and -2% of OMC. Wet mixing is then carried out using the same equipment as used for dry mixing. However, the number of passes for both dry and wet mixing shall be determined by an experimental field study near the site or as per the decision of the site engineer. The wet mix material shall then be spread by mechanical means, finished by a motor grader. Compaction shall be carried out preferably by vibratory rollers of dead weights of 8 to 10 tons to achieve a compacted thickness of 150/200 mm (as per MoRD/MoRTH) as required.

The method of mixing may be decided by the Engineer in charge depending on technical requirements and economical considerations.

When Jarofix is used in fly over's in the retained fill, the mixing and compaction methodology is similar to that as explained in section 4.5.

Compaction/degree of compaction requirements for both National Highway (MoRTH) and Rural Roads (MoRD) are given in **Annexure I**.

4.6 Quality Control Tests

4.6.1 Control Tests for Jarofix collected from Mound

Jarofix may have to be collected from different locations on the mound or different mounds, as per the availability. Different quality control tests viz. dry density; in situ moisture content etc needs to be carried out in the borrow area as per BIS specifications. Tests and their frequency for both National Highways and Rural Roads are given in **Annexure I**.

4.6.2 Acceptance Criteria for Field Compaction

Field dry densities of compacted Jarofix/Jarofix-soil mixes can be evaluated either by core cutter or sand replacement method. The number of tests to be conducted and acceptance criteria for both National Highways and Rural Roads shall be as per MoRTH Specifications for Road and Bridge Works, Section 900 or MoRD specifications, section 1803.2.2. The same has been given in **Annexure I**.

5. PHOSPHOGYPSUM

5.1 Production and Utilization

Phosphogypsum is a waste generated from the fertilizer industry during the preparation of phosphoric acid. It is essentially a 'calcium sulphate' generated from the phosphoric acid plants by the reaction of rock phosphate with sulphuric acid. The production of phosphogypsum is about 12-13 million tons/year in the country from different fertilizer industries (**Fig. 5.1**).

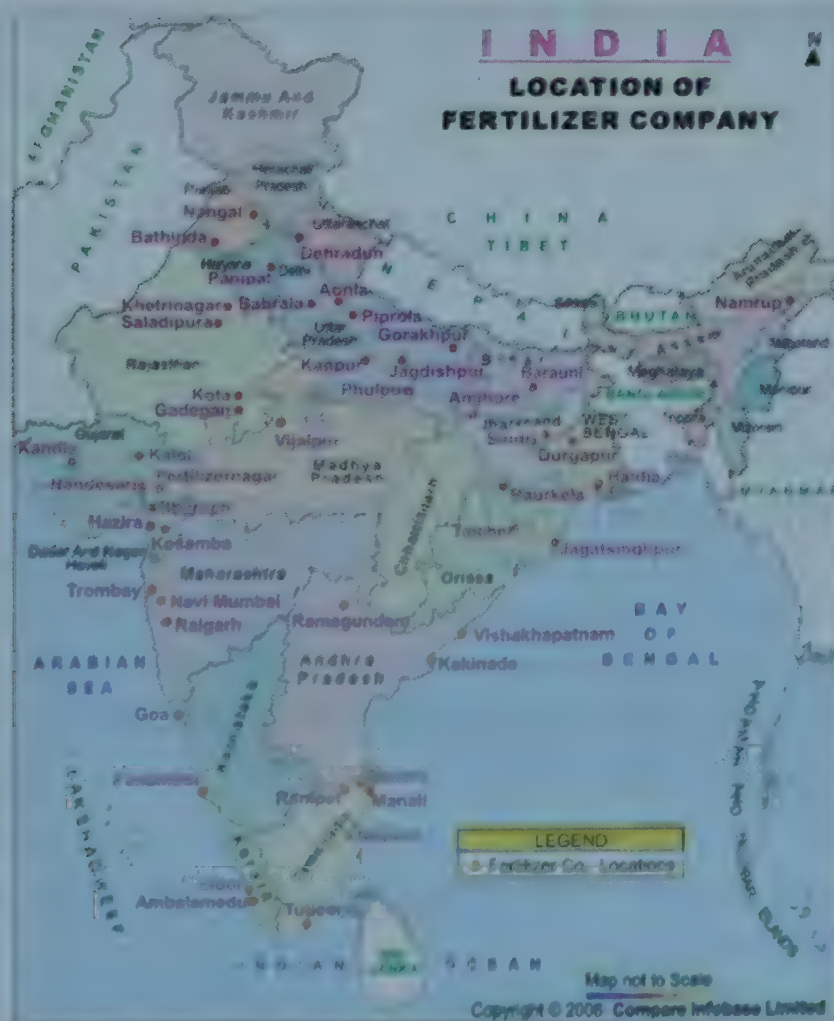


Fig. 5.1 Location of Fertilizer Industries in the Country

Only about 40-50% of generated phosphogypsum is utilized for; cement manufacturing, used as fertilizer in agriculture and for the manufacture of gypsum boards etc. The remaining quantity is dumped in a slurry form in a designated pond without any usage and is occupying costly land and posing threat to the environment. Handling and management of phosphogypsum (dry and wet stacking) is also a major problem in phosphoric acid plants because of the need for a large area required for its disposal and possible release of dust, fluoride and heavy metals to the environment. To have minimal impacts on the environment, Gazette notification (2016 and revised guidelines, if any) from MoEF&CC, shall be followed for safe handling, utilization and disposal of phosphogypsum. The Hazardous Waste (Management, Handling & Transboundary Movement) Rules, 2008 notified under the Environment (Protection) Act, 1986 excluded phosphor-gypsum from the hazardous waste category under Schedule-I and stipulates that the management of phosphogypsum from phosphoric acid fertiliser plants shall be carried out following the guidelines of Central Pollution Control Board (CPCB). The fresh phosphogypsum is treated with lime to achieve the desired pH value before it is disposed of as 'Neutralized/Stabilized phosphogypsum' in the pond. This phosphogypsum which is stable, and when it satisfies the TCLP leachability characteristics, shall be used for road construction.

The bulk utilization of phosphogypsum in road embankment and subgrade would not only ease the disposal problem, provides an alternative to good quality earth and also results in the protection of the environment. CSIR-Central Road Research Institute carried out R&D studies to investigate the potential of phosphogypsum waste material collected from Paradeep, Odisha by detailed laboratory investigations and it was concluded that Phosphogypsum waste can be suitably utilized in place of conventional soil for embankment and subgrade construction. An experimental test track using phosphogypsum was also constructed within the plant premises. The flexible pavement constructed, carried heavily loaded industrial trucks (Details **Annexure-VII**). The results of performance observations for 2 years indicated its suitability for embankment and subgrade construction.

5.2 Physical and Chemical Characteristics

Neutralized Phosphogypsum is grey and is a fine-grained silty material. Typical physical and chemical characteristics have been summarized in **Table 5.1**. The value of specific gravity ranges between 2.3-2.5. The marginally low specific gravity of phosphogypsum as compared to the soil is due to its mineral composition. The natural moisture content varies in the range of 16-20%. This moisture is close to the Optimum Moisture Content (OMC) of phosphogypsum waste. This is an added advantage for using phosphogypsum in road embankment construction. Chemical analysis (**Table 5.1**) indicated that the Phosphogypsum consists primarily of Calcium Oxide (CaO) and Sulphates (SO₄) combined amounts to about >75%. It also consists of small amounts of silica, usually as quartz and unreacted phosphate rock, traces of radioactive material (like radium, uranium), traces of heavy metals namely arsenic, cadmium, chromium, lead and fluoride, the quantity of which shall be less than the regulatory limits specified in MoEF&CC (2016 and revised guidelines, if any).

Table 5.1 Typical Physical and Chemical Characteristics of Phosphogypsum*

S.No.	Characteristic	Values
1	Specific gravity	2.3-2.5
2	Natural moisture content (%)	17-19
3	CaO (%)	29-31
4	SO ₄ (%)	50-53
5	SiO ₂ (%)	5-10
6	P ₂ O ₅ (%)	0.7-1.3
7	Fe ₂ O ₃ (%)	0.1-0.2
8	Al ₂ O ₃ (%)	0.1-0.3
9	pH	2.8-7.4
10	Chloride mg/kg	20-24
11	Calcium (Ca) mg/kg	952-1144
12	Magnesium (Mg)	24-360
13	Cadmium (Cd) mg/kg	0.03-0.26
14	Chromium (Cr)	NT
15	Copper (Cu) mg/kg	0.05-0.12
16	Nickel (Ni) mg/kg	0-0.11
17	Lead (Pb) mg/kg	0.1-0.19
18	Zinc (Zn) mg/kg	0.08-0.48

**Data given are indicative only and may vary depending on the source*

5.3 Geotechnical Characteristics

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of phosphogypsum have been summarized in **Table 5.2**

Table 5.2 Typical Geotechnical Characteristics of Phosphogypsum*

S.No.	Properties	Phosphogypsum
1	Grain Size Analysis	Sand = 16 % Silt = 77 % Clay = 7 %
2	Atterberg Limit Test	Non-plastic

3	Free Swelling Index Test	Non-expansive
4	Specific Gravity Test	2.50
5	Proctor Compaction Test	MDD = 14.8 kN/m ³ OMC = 17 %
6	CBR Test	26 %
7	Direct Shear Test	c = 8 kN/m ² $\phi = 33^{\circ}$
8	Permeability	1.1×10^{-7} m/s

* Typical data only which may slightly vary in different industries.

5.4 Design Specifications and Application Potential

5.4.1 Road Embankment

The geotechnical characteristics of phosphogypsum material viz. plasticity, free swelling and good frictional characteristics indicated its suitability for construction of road embankment. However, due to variation in the lime content, the specific gravity/Maximum Dry Density (MDD) may be slightly lower than as required as per MoRTH specifications. However, MDD values satisfied the requirement as per MoRD specifications. The field performance studies have shown its feasibility for embankment applications. Because of the presence of a high amount of in-situ moisture content, the requirement of additional moisture may be less. However, If the moisture content is above OMC, it shall be dried in the natural sun to achieve the OMC requirement before compaction.

5.4.2 Road Subgrade

Though the phosphogypsum material does not meet the minimum density criteria as specified in MoRTH specifications, the material is having a high CBR value (**Table 5.2**), the material can be suitably used as subgrade material. The performance of phosphogypsum as subgrade material was also ascertained in the field (**Annexure-VII**).

5.4.3 Design Methodology and Typical Cross-Sections

The embankment is designed as a composite structure with phosphogypsum in the core and earth cover on the sides. Earth cover is needed to prevent erosion of the slope of the phosphogypsum layer. For embankment up to 1 m height (In general in Rural Roads), the compacted cover thickness of 0.3 m-0.5 m (measured horizontally) shall be provided. For embankments greater than 1 m height, the compacted thickness of the side cover shall be increased to 1-2 m (measured horizontally). The specification of cover soil shall meet the plasticity, dry density and swelling criteria as specified in MoRD/MoRTH for embankment construction.

The same soil used for cover soil may be used as an intermediate layer. An intermediate layer of compacted thickness 150 (Rural Road)/200 mm (National Highway) is proposed after every 2 m rise in the height. This has been proposed for ease of construction and to provide adequate confinement for the fill material. This would also protect the phosphogypsum material from erosion during possible rainfall during construction.

Phosphogypsum embankment can be designed similar to that adopted for conventional soil embankment. Typical design cross-sections for both National Highway and Rural Road can be arrived at after detailed stability and settlement analysis. Stability analysis needs to be carried out by limit equilibrium method as per IRC:75. Circular failure can be assumed in the analysis. The subsoil characteristics, fill characteristics, and traffic loading conditions need to be considered in the design. The analysis has to be carried out under different moisture conditions and considering the seismic factors. The factor of safety along a critical circle of Jarofix embankment needs to be determined to evaluate the factor of safety. The minimum factor of safety shall be more than 1.25. Settlement analysis shall also be carried out for the design section and shall meet the criteria as per IRC:75

A typical cross-section of the use of phosphogypsum in embankment and subgrade in Industrial premises is shown in **Figs. 5.2 and 5.3**.

5.5 Construction Methodology

Construction of Phosphogypsum embankment and subgrade can be carried out using conventional methods and equipment as per section 305.3 of MoRTH/301.5 of MoRD specifications. The brief methodology of construction has been discussed below;

1. Initially clearing and grubbing, setting out and dewatering of foundation of embankment shall be carried out as per prevalent MoRTH/MoRD specifications. The ground shall then be stripped to a depth of 150 mm, the soil of which may be used as cover soil. The stripped ground shall be compacted to achieve 95% of MDD, IS 2720 (Part 8)-1983 (MoRTH) or 100% of MDD as per IS: 2720 (Part 7)-(MoRTH) before laying of first layer phosphogypsum embankment.
2. The moisture content of the phosphogypsum material shall be checked at the site of placement before the commencement of compaction. The moisture content of phosphogypsum laid for compaction shall normally vary from OMC (determined as per IS: 2720 (Part 7):1983 to $OMC \pm 2$ per cent. It is to be noted that, natural moisture content of phosphogypsum is close to the optimum moisture content.
3. Compaction shall be carried out preferably by vibratory rollers of dead weights of 8 to 10 tons to achieve a compacted thickness of 150/200 mm as required. The cover soil has to be simultaneously compacted along with fill material as the embankment progress upwards. This would provide confinement to phosphogypsum material.

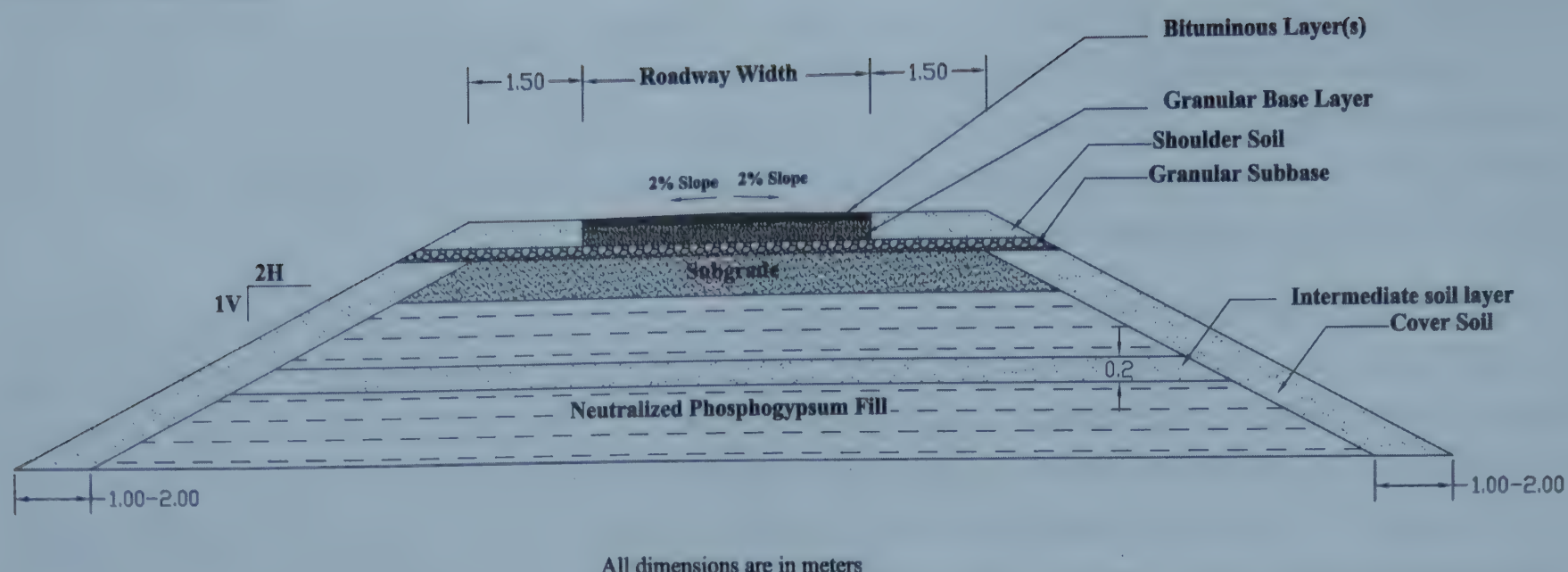


Fig. 5.2 Typical Cross-Section of Phosphogypsum Embankment for National Highway

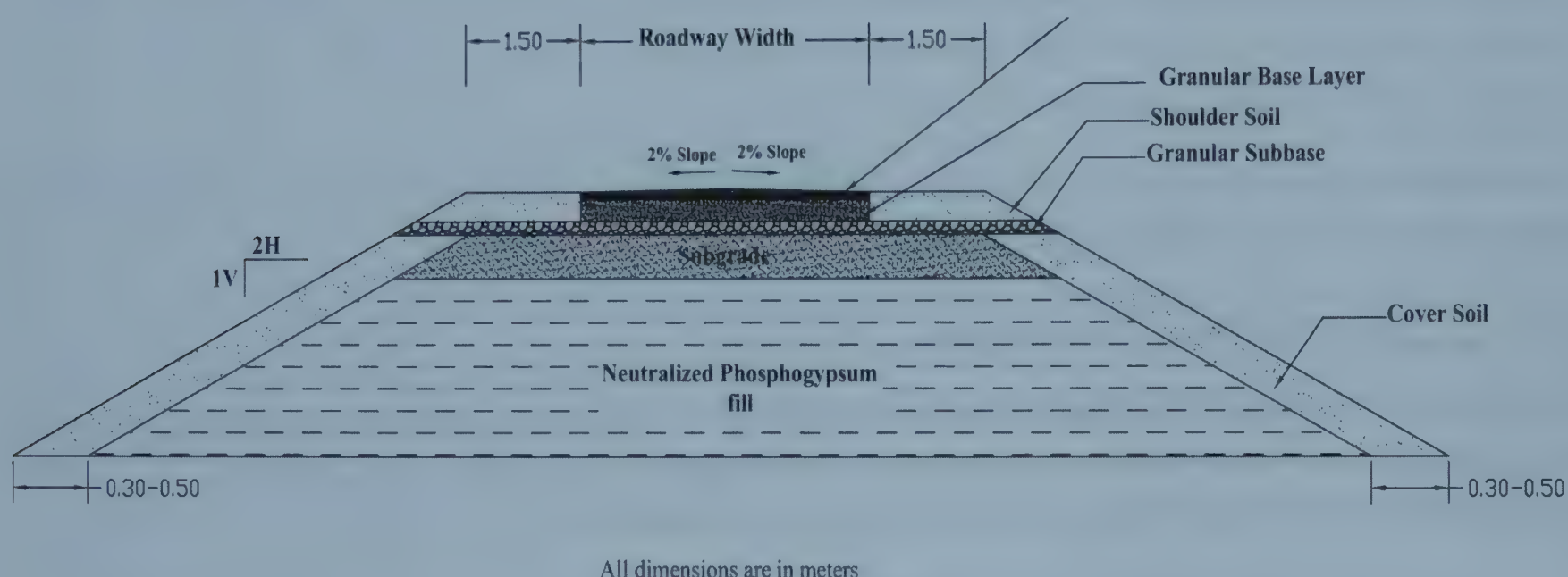


Fig. 5.3 Typical Cross-Section of Phosphogypsum Embankment for Rural Road

5.6 Quality Control Tests

5.6.1 Control Tests for Phosphogypsum collected from Mound

Phosphogypsum may have to be collected from different locations on the mound or different mounds, as per the availability. Different quality control tests viz. dry density; moisture content etc needs to be carried out in the borrow area as per BIS specifications. Tests and their frequency for both National Highways and Rural Roads are given in **Annexure I**

5.6.2 Acceptance Criteria for Field Compaction

Field dry densities of compacted Phosphogypsum can be evaluated either by core cutter or sand replacement method. The number of tests to be conducted and acceptance criteria for both National Highways and Rural Roads shall be as per MoRTH Specifications for Road and Bridge Works, Section 900 or MoRD specifications, section 1803.2.2. The same has been given in **Annexure I**.

6. MARBLE DUST

6.1 Production and Utilization

Around 4000 marble mines and 1100 marble processing units spread over 16 districts of Rajasthan generate a huge quantity of Marble Slurry Dust (MSD), during the processing and slabbing of marble stones, which is about 8 million tons/year. Indiscriminate disposal of Marble Slurry Dust (MSD), mostly on roadsides is causing problems of drainage, air pollution and damage to agricultural land. A literature review indicated the potential of marble slurry dust for road embankment and subgrade. A detailed laboratory and field study carried out by CSIR-Central Road Research Institute indicated its suitability in embankment and subgrade construction. Research studies have also indicated that marble dust in a dosage of 10-30% can also be used to mechanically stabilize the weak soils for improving their plasticity, swelling, shear strength, CBR, Unconfined Compressive Strength (UCS), and permeability characteristics. The improved soil can then be used for embankment and subgrade construction. The utilization of marble dust not only solves the disposal problem, provides an alternative to the conventional good earth and also protects our environment.

6.2 Geotechnical Characteristics

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, and Permeability tests as per BIS standards. Typical geotechnical characteristics of marble dust have been summarized in **Table 6.1**

Table 6.1 Typical Geotechnical Characteristics of Marble Dust*

S.No.	Properties	Marble Dust
1	Grain Size Analysis	100% passing 75 microns IS sieve.
2	Atterberg Limit Test	PI = 7
3	Free Swelling Index Test	Non-expansive
4	Specific Gravity Test	2.7
5	Proctor Compaction Test	MDD = 18.2 kN/m ³ OMC = 12.5 %
6	CBR Test	4 %
7	Direct Shear Test	c = 20 kN/m ² $\phi = 32^{\circ}$

**Data given are indicative only and may vary depending on the source*

6.3 Design Specifications and Application Potential

6.3.1 Road Embankment

Typical geotechnical characteristics of marble dust viz. plasticity; swelling; Maximum Dry

Density (MDD) values (**Table 6.1**) indicated that it satisfied all the requirements as per MoRTH and MoRD criteria for its use in road embankment construction. The material also has good shear strength characteristics. A road embankment can be suitably constructed using 100% MSD waste material using conventional equipment and methodologies. However, considering its erodibility characteristics, the constructed embankment has to be covered with the suitable good earth. Details are discussed in Section 6.4.

6.3.2 *Road Subgrade*

Marble slurry dust material is having a low CBR value, indicating its 100% usage is uneconomical. However, studies have indicated that marble dust can be mixed with local soils in a suitable proportion to achieve the design CBR for pavement design/construction. The optimum proportion of mixing shall be arrived at based on laboratory studies to achieve the required design CBR and also the mix shall satisfy the plasticity, swelling; dry density criteria as per MoRD (Section 301) and MoRTH (Section 305) specifications. An appropriate methodology of mixing may be adopted in the nearby site as discussed in Section 6.5.

6.4 **Design Methodology and Typical Cross-Sections**

The embankment is designed as a composite structure with marble dust in the core and with earth cover on the sides. Earth cover is needed to prevent erosion of the slope of the marble dust layer. For embankment up to 1 m height (In general in Rural Roads), the compacted cover thickness of 0.3 m-0.5 m (measured horizontally) shall be provided. For embankments greater than 1 m height, the compacted thickness of the side cover shall be increased to 1-2 m (measured horizontally). The specification of cover soil shall meet the plasticity, dry density and swelling criteria as specified in MoRD/MoRTH for embankment construction.

The same soil used for cover soil may be used as an intermediate layer. An intermediate layer of compacted thickness 150 (Rural Road)/200 mm (National Highway) is proposed after every 2 m rise in the height. This has been proposed for ease of construction and to provide adequate confinement for the fill material. This would also protect the marble dust material from erosion during possible rainfall during construction.

However, the cross-sections for field implementation shall be finalized based on marble dust geotechnical characteristics, moisture variations, seismic and traffic loading conditions. The minimum factor of safety from the stability analysis shall not be less than 1.25. Settlement analysis shall also be carried out to meet the criteria as per IRC:75.

A typical cross-section of use of marble dust in embankment and subgrade for a National Highway and Rural Road is shown in **Figs. 6.1** and **6.2** respectively.

6.5 **Construction Methodology**

Construction of marble dust embankment/subgrade can be carried out using conventional methods and equipment as per section 305.3 of MoRTH/301.5 of MoRD specifications. The brief methodology of construction has been discussed below;

1. Initially clearing and grubbing, setting out and dewatering of foundation of embankment shall be carried out as per prevalent MoRTH/MoRD specifications. The ground shall then be stripped to a depth of 150 mm, the soil of which may be used as cover soil. The stripped ground shall be compacted to achieve 95% of MDD IS: 2720 (Part 8)-1983 (MoRTH) or 100% of MDD as per IS: 2720 (Part 7)-(MoRTH) before lying of the first layer of marble dust embankment.

2. The moisture content of the marble dust shall be checked at the site of placement before the commencement of compaction. The moisture content of marble dust laid for compaction shall normally vary from OMC (determined as per IS: 2720 (Part 7/Part 8):1983 to $OMC \pm 2$ per cent. The layer can be compacted using vibratory or static rollers as found feasible to achieve the degree of compaction as indicated below.

3. In the case of utilization of marble dust in the subgrade, as discussed earlier marble dust has to be mixed with local soil to meet the CBR requirement/other characteristics as discussed in 6.3.2. An appropriate methodology of mixing may be adopted in the nearby site as discussed below.

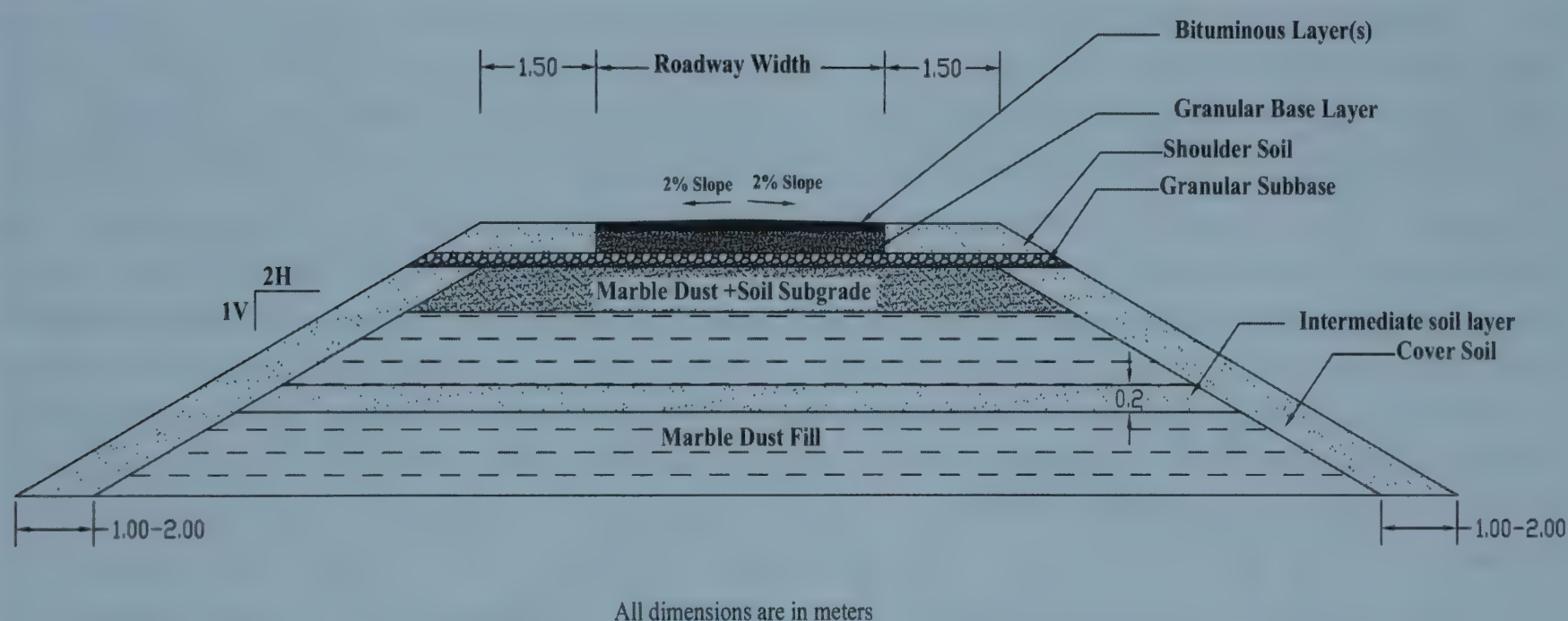


Fig. 6.1 Typical Cross-Section of Marble Dust Embankment for National Highway

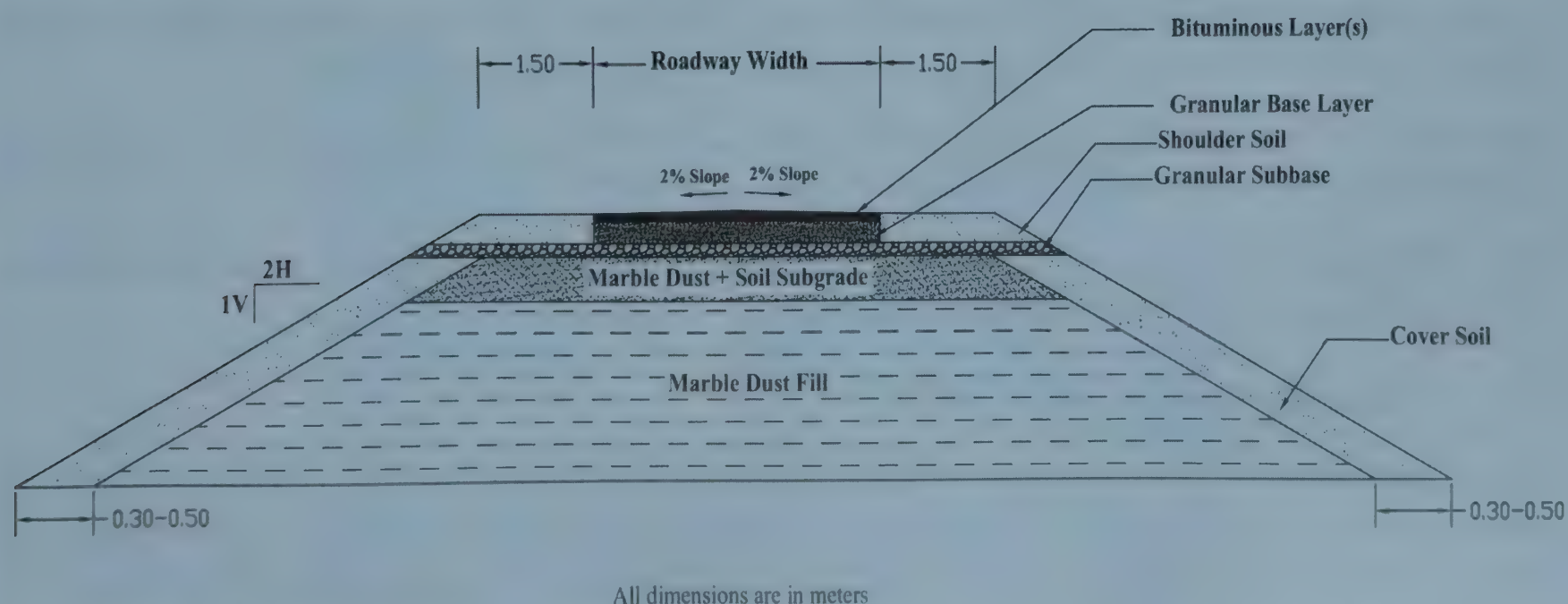


Fig. 6.2 Typical Cross-Section of Marble Dust Embankment for Rural Road

(a) Mixing near the site by Dozers/Rotavator: Mixing of marble dust with local soil shall be carried out on weight (converted to volume as required) depending on the proportion arrived in the laboratory. A stack (cu.m) of marble dust shall be laid in a large spread area and soil/local material (cu.m) is then laid over it. Dozers/Rotavator may be used for thorough mixing. It should be noted that no pockets of unmixed marble dust local shall be visible in the entire volume. The average compaction characteristics of this mix shall be evaluated in the laboratory and this value should be used for quality assessment in the field. The mixed sample is then laid in the field and with the addition of moisture ($OMC \pm 2$ per cent), this can be compacted as per conventional equipment/procedures as per MoRTH/MoRD specifications.

(b) Plant mix stabilization: Pugmill system/WMM plant can be used for mixing marble dust with local soil as per the required designed proportions. The plant mixing ensures uniform homogenous mixing of the materials as per requirement. The wet mix (after the addition of moisture at $OMC \pm 2$ per cent) can then be transported to the place of construction/spread and compacted by conventional equipment/procedures.

(c) In-situ mixing: After preparation of the ground supporting the embankment or top surface of the embankment, Marble dust shall be spread using dozers/graders to the required loose thickness. The local soil shall then be spread over the same to the required loose thickness. The loose thicknesses of each of the fill materials have to be determined for the specified proportion (by weight) and a compacted thickness of 150/200 mm (as per MoRD/MoRTH) as required. The loose layers of marble dust and overlying materials are then dry mixed using a tractor towed harrows or Rotavator till a uniform mix is achieved. 3-4 passes of harrow in either direction (perpendicular) may be sufficient to achieve the uniform mixing. The required amount of water is then added as per the Optimum Moisture Content (OMC) obtained from the Standard/Modified Proctor compaction tests. Water shall be sprinkled from a water tanker fitted with a sprinkler capable of applying water uniformly without any flooding. The moisture content may vary within the range of +1% and -2% of OMC. Wet mixing is then carried out using the same equipment. The number of passes shall be the same as in dry mixing. However, the number of passes for both dry and wet mixing shall be determined by an experimental field study or as per the decision of the site engineer. The wet mix material shall then be spread by mechanical means, finished by a motor grader. Compaction shall be carried out preferably by vibratory rollers of dead weights of 8 to 10 tons to achieve a compacted thickness of 150/200 mm as required.

The method of mixing may be decided by the Engineer in charge depending on technical requirements and economical considerations.

(d) Compaction/degree of compaction requirements for both National Highway (MoRTH) and Rural Roads (MoRD) are given in **Annexure I**.

6.6 Quality Control Tests

Marble dust may be collected from different borrow areas/locations as per the availability. Different quality control tests viz. dry density; moisture content etc needs to be carried out in the borrow area as per BIS specifications. Tests and their frequency for both National Highways and Rural Roads are given in **Annexure I**

6.7 Acceptance Criteria for Field Compaction

Field dry densities of compacted marble dust/marble dust-soil mixes can be evaluated either by core cutter or sand replacement method. The number of tests to be conducted and acceptance criteria for both National Highways and Rural Roads shall be as per MoRTH Specifications for Road and Bridge Works, Section 900 or MoRD specifications, section 1803.2.2. The same has been given in **Annexure I**.

7. OTHER POTENTIAL WASTE MATERIALS

In this chapter, some of the other potential waste materials viz. Foundry sand; Granulated Blast Furnace slag; Redmud; Chrome slag; Municipal Solid Wastes (MSW) available in the country have been discussed. These materials were evaluated in the laboratory and based on their engineering properties, conclusions have been drawn regarding their suitability/applicability in road embankment and subgrade construction. However, no R&D studies have been carried out in the field. The performance of these materials has to be authenticated by construction of an experimental test track and monitoring over some time. However, the implementing authorities, are advised to go ahead with the construction of small lengths of road stretches with these materials and the experience gained can be utilized for their large scale field applications.

7.1 Foundry Sand

Foundry sand is an industrial waste material generated from the foundry industries spread all over the country (**Fig. 7.1**).



Fig. 7.1 Location Map of Foundry Industries in India

Natural sand is used as a moulding material in the ferrous and nonferrous metal casting industries. This sand is typically recycled and reused through many production cycles, however, about 5-10% is generated as waste each year. After several cycles, it is not suitable for the industry and this piles up as a waste material called foundry sand. The total production of foundry sand is about 3 million tons annually. The high temperatures involved in the casting process make the majority of the sands inert, with very little pollution potential. A literature review indicates that foundry sand was successfully used for the construction of road embankment abroad and its performance was comparable to conventional soil. CSIR-Central Road Research Institute investigated foundry sand samples collected from 10 different industries in the country and concluded about its potential for road embankment and subgrade construction.

7.1.1 *Typical Geotechnical Characteristics*

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, shear strength tests, California Bearing Ratio (CBR) tests, and Permeability tests as per BIS standards. Typical geotechnical characteristics of foundry sand have been summarized in **Table 7.1**

Table 7.1 Typical Geotechnical Characteristics of Foundry Sand*

S.No.	Properties	Foundry sand
1	Grain Size Analysis	Sand = 76-96 %, Silt = 4-13 %, Clay = 1-10 %
2	Atterberg Limit Test	Non-plastic
3	Free Swelling Index Test	0-43 %
4	Specific Gravity Test	2-2.63
5	Proctor Compaction Test	MDD = 16-19 kN/m ³ OMC = 11-15 %
6	CBR Test	23-35 %
7	Direct Shear Test	c = 6-19 kN/m ² ϕ = 26-37°

**Data given are indicative only and may vary depending on the source*

7.1.2 *Application Potential*

7.1.2.1 *Road Embankment and Subgrade*

Typical geotechnical characteristics of foundry sand viz. plasticity and swelling characteristics; Maximum Dry Density (MDD), and CBR values (**Table 7.1**) indicated that it satisfied all the requirements as per MoRTH and MoRD criteria for its use in road embankment and subgrade construction. A road embankment and subgrade can be constructed using 100% foundry sand.

however, considering its erodibility characteristics, the constructed embankment/subgrade may be confined/covered with the suitable good earth.

7.2 Granulated Blast Furnace Slag

Granulated Blast Furnace Slag (GBFS), is an industrial waste generated in the steel plants during the extraction of iron from iron ores, and they are normally dumped in and around the plant occupying costly land. The dumpsite is also causing significant environmental pollution in the surrounding area. The slag is produced when the molten slag is rapidly quenched/suddenly cooled in water during the iron manufacturing process. The slag resembles the cohesionless granular material with predominantly sand-size particles. The quantity of different types of steel slag produced in the country is around 10-12 MT per year, of which GBFS forms a substantial part. At present, GBFS is mainly used for cement manufacturing. CSIR-Central Road Research Institute had carried out both laboratory and field R&D studies on GBFS collected from both the Visakhapatnam Steel plant and Rourkela steel plant. It was concluded that 100% GBFS and stabilized GBFS (mechanical and chemical) could be successfully used for sub-base and base layers of road pavement, replacing the conventional granular layers. Literature also indicated that granulated blast furnace slag material can also be used for mechanical stabilization of weak soil, and their optimized mixes can be used for the construction of highway embankment and subgrade.

7.2.1 Typical Chemical Characteristics

Typical chemical characteristics of Granulated Blast Furnace Slag are given in **Table.7.2**

Table 7.2 Chemical Characteristics of Granulated Blast Furnace Slag*

S.No.	Chemical Composition	Amount (%)
1	CaO	30-40 %
2	SiO ₂	15-35 %
3	Al ₂ O ₃	15-40 %
4	MgO	8-11 %
5	FeO	5 % max
6	MnO	2 % max

**Data given are indicative only and may vary depending on the source*

7.2.2 Typical Geotechnical Characteristics

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of Granulated Blast Furnace Slag have been summarized in **Table 7.3**

Table 7.3 Typical Geotechnical Characteristics of Granulated Blast Furnace Slag*

S.No.	Properties	Granulated Blast Furnace Slag
1	Grain Size Analysis	Sand = 99%, Silt & Clay = 1%
2	Atterberg Limit Test	Non plastic
3	Water Absorption Test	2-4%
4	Specific Gravity Test	2.45-2.65
5	Proctor Compaction Test	MDD = 12-14 kN/m ³ OMC = 8-12 %
6	Direct Shear Test	c = 2-5kPa $\phi = 35-40^\circ$

**Data given are indicative only and may vary depending on the source*

7.2.3 Application Potential

7.2.3.1 Road Embankment and Subgrade

The non-plastic, high shear strength characteristics nature of GBFS material indicated its potential for embankment construction. GBFS can be mechanically stabilized with local soil in the required design proportion for use in embankment construction. However considering its erodibility characteristics, the constructed GBFS/GBFS-soil mix, embankment needs to be confined/covered with suitable good earth of design thickness. The designed GBFS-soil mix can also be used as the subgrade. Chemically stabilized GBFS mix can be effectively used for the construction of sub-base and base layers of road pavement.

7.3 Redmud

Red mud is a waste generated during the refining of bauxite, to produce alumina (aluminium oxide). There are two processes for alumina production, viz. Bayer and sintering processes. In India, alumina is generally produced from the Bayer process. In this process, Bauxite ore is heated in a pressure vessel along with a sodium hydroxide solution at a temperature of 150 to 200°C. Bauxite, the most important ore of aluminium, contains a significant quantity of aluminium oxide (Al_2O_3) and when it is purified/refined to aluminium metal, the rest residue slurry is formed as red mud waste. This process generates red mud with a very high water content (about 50%) and is again mixed with water to dispose of off in lean slurry form to the ponds. In India, about 4 million tons of red mud is produced annually without having much usage. View of red mud tailing pond and dry red mud is shown in **Figs. 7.2 (a)** and **7.2(b)** respectively.



Fig. 7.2 (a) Red Mud Tailing Pond



7.2 (b) View of Dry Red Mud

CSIR-Central Road Research Institute studied the geotechnical characteristics of red mud and concluded about its potential in road embankment construction. Literature also indicated that redmud+fly ash can also be suitably used for embankment construction. The per cent red mud shall be optimized in the laboratory, considering MoRD/MoRTH specifications.

7.3.1 Typical Chemical Characteristics

Typical chemical characteristics of Red Mud are given in **Table 7.4**. Red mud mainly consists of Iron oxide (Fe_2O_3) and Aluminium oxide (Al_2O_3).

Table 7.4 Typical Chemical Characteristics of Red Mud*

S.No.	Chemical Composition	Amount (%)
1	Fe_2O_3	30-60%
2	Al_2O_3	10-20%
3	TiO_2	0-25%
4	Na_2O	2-10%
5	SiO_2	10-20%
6	CaO	2-8%

**Data given are indicative only and may vary depending on the source*

However, there may be a presence of heavy metals and other toxic elements in the red mud, its Neutralization/stabilization is required at the source. The responsibility of neutralization/stabilization lies with the Industry. The quantity of heavy metals and other toxic elements shall be within the regulatory limits as specified in MoEF&CC (2016 and revised guidelines, if any).

7.3.2 Typical Geotechnical Characteristics

Detailed geotechnical characteristics need to be studied to investigate its feasibility for embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of red mud have been summarized in **Table 7.5**

Table 7.5 Typical Geotechnical Characteristics of Red Mud*

S.No.	Properties	Red Mud
1	Grain Size Analysis	Sand = 28 % Silt = 49 % Clay = 23 %
2	Atterberg Limit Test	Non-plastic
3	Free Swelling Index Test	5
4	Specific Gravity Test	3.3
5	Proctor Compaction Test	MDD = 18.6 kN/m ³ OMC = 19 %
6	CBR Test	26 %
7	Direct Shear Test	c = 11 kN/m ² $\phi = 27^\circ$
8	Permeability	3.7×10^{-7} m/s
9	Compresssion Index, Cc	0.13

*Data given are indicative only and may vary depending on the source

7.3.3 Application Potential

7.3.3.1 Road Embankment and Subgrade

Typical geotechnical characteristics of redmud viz. plasticity; swelling; Maximum Dry Density (MDD), CBR values (**Table 7.5**) indicated that it satisfied all the requirements as per MoRTH and MoRD criteria for its use in road embankment and subgrade construction. A road embankment and subgrade can be constructed using 100% red mud, however, considering its erodibility characteristics, the constructed embankment/subgrade may be confined/covered with the suitable good earth.

7.4 Chrome Slag

Chrome slag is one of the waste materials, produced during the extraction of chrome from its concentrate ore. In this process, molten concentrate chrome ore is poured in concrete buckets, chrome metal being heavier, settle at the bottom, while lighter slag, gets separated. The slag is crushed into sizes viz. coarser slag, Type A (> 10 mm) and finer slag, Type B (< 10 mm)

(Fig. 7.3). The production of chrome slag is about 2 lac tons per year. Presently, it is utilized in limited quantity in civil construction, landfilling etc. A literature review indicated that chrome slag can be effectively used for the construction of embankment and pavement layers. CSIR-Central Road Research Institute, through their R&D laboratory study, concluded that Type 'B' chrome slag can be successfully used for embankment construction.



Fig. 7.3 View of Dumped Type B Chrome Slag

7.4.1 *Typical Chemical Constituents of Chrome Slag*

Typical chemical characteristics of chrome slag are shown in **Table 7.6**. Chrome slag mainly consists of oxides of Mg, Si, Al, Cr and traces of Ca, Fe.

Table 7.6 Chemical Constituents of Chrome Slag*

Constituents	Amount (%)
Cr_2O_3	10-12
FeO	1-2
SiO_2	28-30
Al_2O_3	22-24
CaO	6-8
MgO	26-28

**Data given are indicative only and may vary depending on the source*

7.4.2 *Typical Geotechnical Characteristics*

As discussed earlier, Type 'B' chrome slag has the potential for use in embankment and subgrade. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, California Bearing Ratio (CBR) tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of Type B chrome slag have been summarized in **Table 7.7**.

Table 7.7 Typical Geotechnical Characteristics of Type B Chrome Slag

S.No.	Properties	Type B, Chrome Slag
1	Grain Size Analysis	Gravel = 41 % Sand = 57 % Silt = 2 %
2	Atterberg Limit Test	Non-plastic
3	Free Swelling Index Test	Non-swelling
4	Specific Gravity Test	3.2
5	Relative Density Parameters	Max Dry Density = 22.8 kN/m ³ , Min Dry Density = 19.1 kN/m ³
6	CBR Test	16 %
7	Direct Shear Test	$c = 10 \text{ kN/m}^2$ $\phi = 40^\circ$
8	Permeability	$8 \times 10^{-4} \text{ m/s}$

*Data given are indicative only and may vary depending on the source

7.4.3 Application Potential

7.4.3.1 Road Embankment and Subgrade

Typical geotechnical characteristics of Type 'B' viz. Non-plastic and Non-swelling nature; and the values of Maximum Dry Density (MDD) and CBR (**Table 7.7**) indicated that it satisfied all the requirements as per MoRTH and MoRD criteria for its use in road embankment and subgrade construction. A road embankment and subgrade can be constructed using 100% Type 'B'; chrome slag, however, considering its erodibility characteristics, the constructed embankment/subgrade may be confined/covered with the suitable good earth.

7.5 Municipal Solid Wastes

The rapid growth of population, industrialisation and urbanisation during the last few decades has resulted in the generation of huge quantities of Municipal Solid Wastes (MSW) in different cities. Different constituents of this waste dump include; groceries, food scraps, vegetable remains, packing materials, paper, remains of used coal, ash, wood, metals, plastics, ceramics, cloth, glass etc and even the construction demolition (C&D) wastes. In India, about 60 million tonnes of MSW has generated annually and is disposed of in identified landfills in different cities. These landfills are affecting the health, hygiene, sanitation and aesthetics of the surrounding area. If these wastes are not properly disposed of, this can prove a perilous and environmental hazard. CSIR-Central Road Research Institute carried out detailed laboratory research work on MSW collected from Ghazipur, Delhi and Varanasi, Uttar Pradesh. It was concluded from the R&D studies that 60-75% of landfill wastes can be suitably used in embankment construction. View of a typical landfill at Ghazipur dumpsite, New Delhi and the segregated MSW proposed to be used in embankment construction is shown in **Figs. 7.4** and **7.5** respectively.



Fig. 7.4 View of MSW Landfill, Ghazipur, Delhi

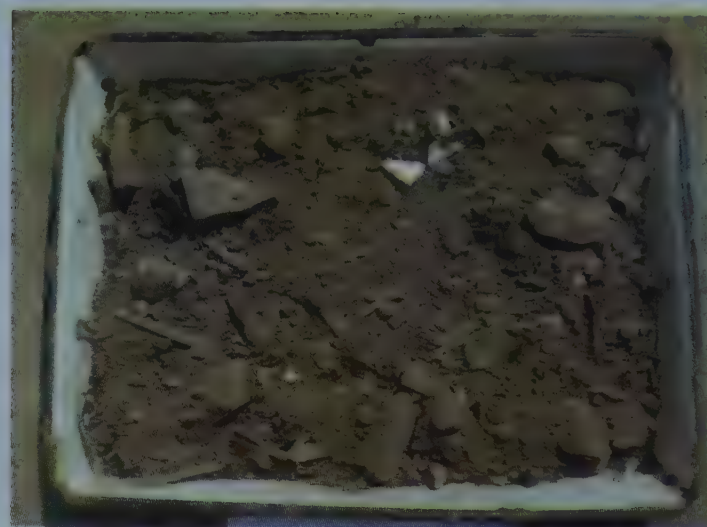


Fig 7.5 View of Segregated MSW

7.5.1 *Process of Segregation*

The Municipal Solid Waste (MSW) from the landfill is a heterogeneous material and cannot be used as such in embankment construction. It has large size plastics, clothes and even boulder size C&D waste. MSW needs to be dried and segregated/separated into different suitable sizes, by using segregation plants installed near the landfill. The segregated materials need to be tested for their toxicity/leachate characteristics (Section 7.5.2) before using in road embankment construction. The segregated wastes also need to be evaluated for their geotechnical characteristics (Section 7.5.3); suitably designed; also needs to be evaluated for slope stability/settlement analysis, especially when used for high MSW embankments. Conventional methods and equipment may be used for compaction in the field.

7.5.2 *Leachate Characteristics*

The segregated MSW waste, proposed to be used for embankment construction, needs to be tested for the presence of heavy metals viz. Zn, Cd, Pb, Hg, Co, Cr etc. The environmental requirement as discussed in Section 1.2 needs to be strictly adhered to before using the material for road embankment construction.

7.5.3 *Typical Geotechnical Characteristics*

Detailed geotechnical characteristics need to be studied to investigate the feasibility of segregated MSW for road embankment construction. Different geotechnical tests which have to be carried out includes viz. Grain size analysis, Standard Proctor compaction tests, Direct shear tests, Consolidation tests, Permeability tests as per BIS standards. Typical geotechnical characteristics of Segregated MSW have been summarized in **Table 7.8**

Table 7.8 Typical Geotechnical Characteristics of Segregated Municipal Solid Wastes*

S.No.	Properties	Municipal Solid Waste
1	Grain Size Analysis	Gravel = 31-39 %, Sand = 30-37 % Silt = 24-27 % Clay = 4-5 %
2	Atterberg Limit Test	Non-plastic
3	Free Swelling Index Test	12-24
4	Specific Gravity Test	1.8-2.23
5	Proctor Compaction Test	MDD = 15-18 kN/m ³ OMC = 15-19 %
6	Direct Shear Test	c = 10-25 kN/m ² ϕ = 28-38°
7	Permeability	$1.2 \times 10^{-8} - 2 \times 10^{-9}$ m/s
8	Compression Index, Cc	0.14-0.19

*Data given are indicative only and may vary depending on the source and size of the segregated MSW

7.5.4 Application Potential

7.5.4.1 Road Embankment

Segregated Municipal Solid Waste (MSW) has the potential to be used as an embankment material in both Rural Roads and National Highways. The segregated MSW shall be < 75 mm, as specified in the MoRTH specification as a requirement for conventional soil.

8. SUSTAINABILITY AND ENVIRONMENTAL IMPACT

Sustainable development is a holistic practice that includes efforts to mitigate negative effects on every part of the road infrastructure. Sustainable construction must consider the interconnected issues under social, economic and environmental areas. The need to plan for sustainable construction is evident since global warming possesses significant challenges for cities. Saving of costly mother earth and utilization of waste as a resource contributes to the environmental and societal benefit.

Economic and Social benefits: Depletion of natural resources has increased the cost of transportation, which in turn increases, tremendously the total cost of road construction. The use of locally available industrial wastes economises the total cost of construction. The effective usage of wastes not only provides an alternative and also vacates the dumping area. The costly dumping area can be effectively utilized for societal developmental work.

Environmental benefit: Conservation of fertile soil by utilization of wastes leads to sustainable road construction. The utilization of wastes also reduces the environmental cost of quarrying substantially. There is a reduction in carbon footprint in the form of Greenhouse gas emissions (CO₂ & CH₄).

QUALITY CONTROL TESTS AND ACCEPTANCE CRITERIA FOR FIELD COMPACTION

I. Quality Control Tests and their Frequencies

Tests and their frequency for both National Highways (MoRTH) and Rural Roads (MoRD) are given below;

Table I.1 Quality Control Tests and their Frequencies

Type	Frequency	
	National Highway	Rural Roads
Sand content IS:2720-Part 4	2 tests per 3000 cu.m	One test from each source for one km or part thereof
Plasticity Index	Each type, 2 tests	-do-
Dry density	Each type, 2 tests ((IS:2720-Part 8)	-do- (IS:2720-Part 7)
Moisture content	Two tests	- do-
Deleterious content (IS:2720: Part 22 and Part 27)	As and when required by the Engineer.	-do-

II. Dry Density Requirements

The density requirements of waste materials to be used for the construction of both National Highway and Rural Roads is given below;

Table I.2 Dry Density Requirements for both National Highway and Rural Road

Type	Field Condition	Embankment	Subgrade
National Highway (As per IS:2720 – Part-8)	Embankments up to 3m in height not subject to extensive flooding.	$\geq 15.2 \text{ kN/m}^3$	$\geq 17.5 \text{ kN/m}^3$
	Embankments more than 3m height subject to a long period of inundation.	$\geq 16 \text{ kN/m}^3$	
Rural Roads (As per IS:2720 –Part -7)	Embankments not subject to flooding	$\geq 14.4 \text{ kN/m}^3$	$\geq 16.5 \text{ kN/m}^3$
	Embankments subject to flooding and more than 3m in height.	$\geq 15.2 \text{ kN/m}^3$	

III. Compaction Requirements

The required degree of compaction to be achieved in the field for both National Highway and Rural Roads is given below;

Table I.3 Requirements of Compaction for both National Highways and Rural Roads

Type	Laboratory Condition	Embankment	Subgrade
Rural Road	Minimum dry density after compaction as a percentage of MDD IS:2720 (Part 7)-1983	98%	100%
National Highway	Minimum dry density after compaction as a percentage of MDD IS:2720 (Part 8)-1983	95%	97%

IV. Acceptance Criteria for Field Compaction

(A) National Highways

Field dry densities can be carried out either by the core cutter or sand replacement method. The number of tests to be conducted and acceptance criteria shall be as per in MoRTH Specifications for Road and Bridge Works, Section 900. For earthwork in the embankment, control shall be exercised on each layer by taking at least one set of ten measurements of density for each 3000 sq.m of compacted area, or closer as required to yield the minimum number of tests results for evaluating a day's work on a statistical basis. The acceptance criteria shall be subject to the condition that the mean density is not less than the specified density +

$$\left(1.65 - \frac{1.65}{(\text{No. of samples})^{0.5}} \right) \text{ times the standard deviation}$$

However, for earthwork in shoulders (earthen) and in the subgrade, at least one set of ten density measurements shall be taken for every 2000 sq.m for the compacted area.

(B) Rural Road

The number of tests to be conducted and acceptance criteria shall be as per in MoRD specifications, Section 1803.2.2. The average of 3 dry density tests in-situ shall not be less than a specified degree of compaction. Individual test values shall not be less than 1% of the specified value of the degree of compaction.

CASE HISTORIES

ANNEXURE II

UTILIZATION OF FLY ASH FOR HIGHWAY EMBANKMENT CONSTRUCTION, NEW DELHI

CSIR-Central Road Research Institute (CRRI) carried out detailed laboratory and field studies to investigate the feasibility of Fly ash in the construction of the Nizamuddin approach embankment (NH-9). After the development of technical and design specifications in the laboratory, about 2 km length of Fly ash embankment was constructed along the river bed the Yamuna. The height of the fly ash embankment varied between 6-9 m. In total, about 1.5 lakh cubic metres of fly ash was utilized and there was saving to the authorities to the tune of rupees 1 crore. Conventional rollers and equipment were used for field construction and the quality was assessed as per MoRTH specifications. Gravel/Moorum soil was laid on the top of the embankment for a thickness of 500 mm in two layers and compacted to form the subgrade. Side soil cover was protected by providing 200 mm thick filter media consists of 12 mm size aggregates. The slope of the embankment was protected by stone pitching, using boulders of diameter 300 mm with a minimum weight of 40 kg. During construction, the embankment was also instrumented to monitor the post-construction performance. There was no significant settlement; pore water pressure development and at present, it is in very good condition. A typical cross-section of fly ash embankment constructed with a construction photograph is shown in **Figs. II.1 and II.2**.

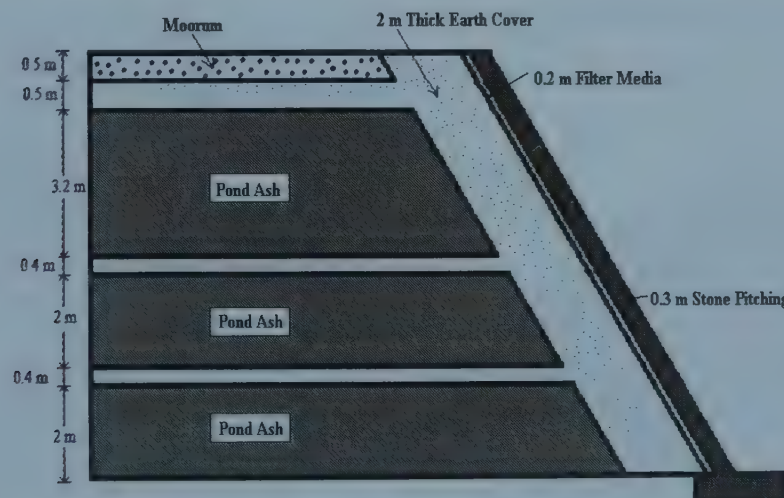


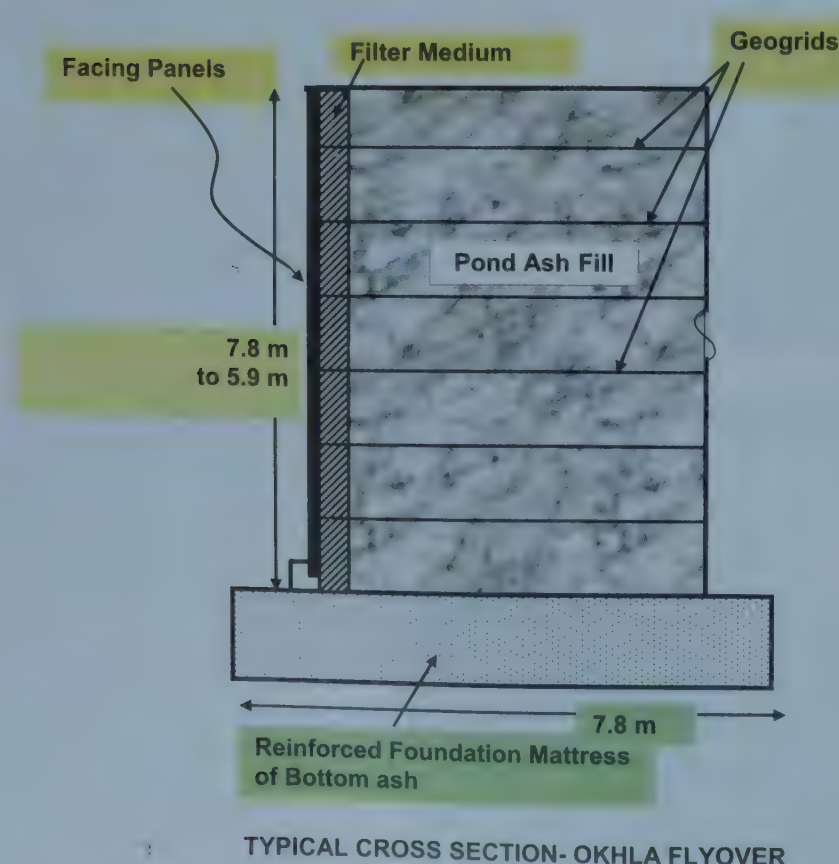
Fig. II.1 Cross Section of Nizamuddin Approach Fly ash Embankment (NH-9)



Fig. II.2 Construction Photograph (NH-9)

VISHVESHWARAYA SETU (OKHLA FLYOVER) REINFORCED FLY ASH EMBANKMENT, NEW DELHI

Delhi PWD in association with CSIR-Central Road Research Institute and Fly Ash Mission constructed the first reinforced fly ash approach embankment (RE wall) on one side of the slip roads adjoining NH-2, along Mathura Road, New Delhi. The length of the RE wall embankment constructed was 59 m; with the height varying between 5.9 m to 7.8 m. Some portion of the eastern slip road was very close to the boundary of the project area. Construction of a conventional RCC retaining wall would have resulted in its foundation encroaching into the adjacent land, thereby necessitating its acquisition. This eventuality was avoided by constructing the reinforced fly ash approach embankment in this portion of the slip road. A conventional retaining wall was provided in the remaining length. The typical cross-section of the Reinforced fly ash embankment and construction photographs are shown in **Fig. III.1**. Bottom ash was filled in two layers up to a height of 0.5 m in the foundation. Each layer was compacted to 95 per cent of MDD. Bi-orientated geogrid was spread over the compacted fill to increase the Factor of Safety against bearing. Compaction was carried out by 8-ton static roller followed by the vibratory roller. A trench, 500 mm x 580 mm was excavated in the filled up soil and an 80 mm thick levelling course of concrete was laid, followed by casting of 'U' shaped foundation block in M 20 concrete, for inserting the facing panels. Precast facing panels of 150 mm thickness and size varying from 0.98 m x 2 m to 0.98 m x 2.8 m were provided with tongue and groove arrangement for connecting the panels. Anchorage geogrid was embedded while casting the panels.



View of (a) Reinforced Fly ash Portion
(b) Geogrid Reinforced Bottom ash

Fig. III.1 Typical Cross-Section of Reinforced Fly ash Embankment and Construction Photographs

SARITA VIHAR FLYOVER REINFORCED APPROACH EMBANKMENT USING FLY ASH, NEW DELHI

The construction of the Sarita Vihar Flyover reinforced approach embankment was taken up by the Delhi Development Authority in association with CSIR-Central Road Research Institute, New Delhi. The approach embankment has a divided carriageway with 3 lanes on each side. The approach embankment was constructed using Reinforced Earth (RE) technology. The length of reinforced earth wall approaches on either side was 105 m and 78 m. The maximum height of the wall was 5 m. For reinforcement, polymeric strips were used. Two types of ties, which have an ultimate tensile load capacity of 50 tonnes and 30 tonnes, were used in this project. The friction ties were composed of high tenacity polyester yarns and can undergo deformation to the extent of 10 to 12 per cent without undergoing any failure. The ties were tested for resistance against creep, chemicals, low temperature, high temperature, biological degradation and pullout test as per relevant codes and reported to be acceptable. Pond ash from the nearby Badarpur thermal power station was used as backfill material. The angle of internal friction of pond ash was found to be varying from 32° to 36° . The structure was designed as per the guidelines given in BS 8006:1995. The facing panels were cast in-situ and construction work was taken up by using pond ash as backfill. Static and vibratory rollers were employed to compact the pond ash. Near the facing panel pond, ash was compacted using plate vibrators. Typical view during construction and finished RE wall is shown below in **Fig. IV.1**.



Fig. IV.1 View of (a) Reinforced Fly ash Portion (b) Finished RE Wall

UTILIZATION OF COPPER SLAG IN HIGHWAY CONSTRUCTION, TUTICORIN, TAMIL NADU

CSIR-Central Road Research Institute (CRRI) carried out a detailed laboratory and field study to investigate the feasibility of coarse copper slag in the construction of embankment and the bituminous concrete mix. By laboratory studies, it was concluded that copper slag has the potential for use in embankment fill applications, Granular Sub Base (GSB), Wet Mix Macadam Bases and in Bituminous mixes. About 50-100% of copper slag can be used instead of soil, in embankment construction whereas, about 20-30% of copper slag can replace conventional fine aggregates in sub-base, base and bituminous construction. About 0.5 km stretch of bridge approach embankment on Madurai-Tuticorin Highway (NH-45B) was constructed with coarse copper slag with the support of the National Highway Authority of India (NHAI). The height of the copper slag embankment varied from 1 m to 4 m. As the construction of 100% copper slag was not practically feasible, the material was mixed with locally available Fly ash/local soil by 50%. The slope of the embankment was protected with 2 m thick selected good earth. The pavement performance of the finished copper slag embankment was evaluated by field studies for 3 years. The settlement; roughness and deflection data collected indicated its good performance as compared to convention soil embankment. The construction of copper slag embankment and its field evaluation is shown in **Fig. V.1**.



Spreading of Copper Slag



Field Evaluation by DCP Test



Compacted Copper Slag-Fly ash



View of Copper Slag Finished Road

Fig. V.1 Construction of Copper Slag Embankment and its Field Evaluation

UTILIZATION OF JAROFIX IN HIGHWAY CONSTRUCTION- CHITTORGARH, RAJASTHAN

CSIR-Central Road Research Institute carried out a project at Chittorgarh, Rajasthan to explore the possibility of using Jarofix waste material for the construction of embankment and subgrade layer. A 300 m experimental test track was constructed during the widening of two lanes to four lanes along Dabok – Mavli Chittorgarh road (SH-9). The test track site is located near Mungana Village, 44 km from Chittorgarh. Jarofix was used on the right side of the widening portion of the road towards Chittorgarh. To compare the performance of Jarofix as an embankment and subgrade material vis-a-vis conventional soil, the test length provided for this purpose was divided into four sections. These sections were constructed by using conventional local soil/Jarofix/Jarofix-soil mix in different proportions in the embankment and subgrade of road pavement. The height of the embankment was 2 m and was constructed with a slope of 2H: 1V. During the construction, geotechnical parameters i.e. density, moisture content, in-situ CBR, settlement, modulus of elasticity etc. were evaluated. The pavement performance of the finished test section was evaluated by Benkelman beam, topographic and roughness survey. It was concluded that 100% Jarofix can be used for embankment construction, while mechanically stabilized Jarofix (50%)+soil (50%) can be used for subgrade construction. The construction of Jarofix embankment and its field evaluation is shown in **Fig. VI.1**.

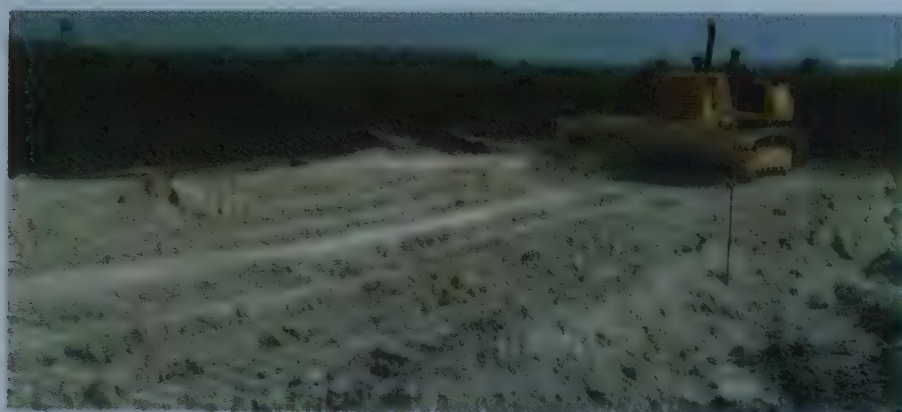


View of (a) Stabilization of Jarofix (b) Strength Evaluation (c) Finished Road

Fig VI.1 Construction of Jarofix Embankment and its Field Evaluation

UTILIZATION OF PHOSPHOGYPSUM IN HIGHWAY CONSTRUCTION, PARADIP, ODISHA

CSIR-Central Road Research Institute carried out R&D project to explore the feasibility of phosphogypsum for road embankment and subgrade construction. The laboratory studies indicated its potential for use in embankment; subgrade and subbase layers of road pavement. To investigate its field feasibility, a 400 m single lane experimental test track was constructed at Paradeep, Odisha. The road runs over a waterlogged area with soft weak subsoil. The constructed road carries heavily loaded trucks carrying phosphogypsum waste and other raw materials for phosphoric acid production. The height and slope of the embankment were 1m constructed with a slope of 2H:1V. The thickness of the subgrade was 500 mm. Conventional rollers and equipment were used for construction. The pavement performance of the finished test section was evaluated by settlement; deflection and roughness surveys. The performance of phosphogypsum was as good as conventional sand embankment. It was concluded that 100% of phosphogypsum can be used for both embankment and subgrade construction. Growth of vegetation was also observed over the phosphogypsum slope after a while. The construction of phosphogypsum embankment and its field evaluation is shown in **Fig. VII.1**.



Spreading of Phosphogypsum by Grader



**Finished Phosphogypsum
Embankment Layer (with cover soil)**



DCP test on Phosphogypsum Embankment



Finished Road

Fig. VII.1 Construction of Phosphogypsum Embankment and its Field Evaluation

REFERENCES

Fly Ash

1. Pandian, N.S., Rajasekhar, C, and Sridharan, A. (1996). Fly ash as a Pre-filter Material for the Retention of Lead ions, *Journal of Testing and Evaluation*, 24(3),181-185.
2. Sridharan, A., Pandian, N.S. and Rajasekhar, C (1996). Influence of pH on the Retention of Heavy Metal Ions by Fly ash, *Proceedings of 2nd International Congress on Environmental Geotechnics*, 1, 603-608.
3. Shivakumar, D.S. and Datta, M. (1996). Assessment of Groundwater Contamination Potential around Ash Ponds through Field Sampling. A review, *Proceedings of Conference on Ash Ponds and Disposal Systems*, New Delhi, 311-325.
4. CSIR-CRRI Report (1999). Utilization of Fly ash in Eastern Approach Embankment for Second Nizamuddin Bridge, Public Works Department, New Delhi.
5. CSIR-CRRI Report (2000). Characteristics of Pond ash and Bottom ash for use in Sarita Vihar Flyover Approach Embankment, Gammon India Ltd., Mumbai.
6. Havanagi, V.G. (2000). Geotechnical Characterization, Strength, Erosion Aspects of Fly ash-Soil Mixtures, PhD thesis, Indian Institute of Technology, New Delhi.
7. CSIR-CRRI Report (2000). Design and Construction of Fly ash Embankment from Dankuni to Kolaghat Road Section on NH-6, Department of Science and Technology, New Delhi.
8. CSIR-CRRI Report (2001). Construction of Sarita Vihar Flyover Reinforced Approach Embankment using Fly ash, Delhi Development Authority, New Delhi.
9. Vittal U.K., Havanagi, V.G., Mathur, S., Sikdar, P.K. (2002). Evaluating Fly ash as an Alternative Construction Material for Road Embankments, *Proceedings of National Seminar. On-Road Transportation in India: Emerging Trends and Techniques*, Sept 12-13, Kharagpur, 3.73-3.84.
10. IRC:SP:58 (2001). Guidelines for Use of Fly ash in Road Embankment, Indian Roads Congress, New Delhi, India.
11. CSIR-CRRI Report (2006). Design and Supervision of Pond Ash Embankment from Shastri Chowk to Khajouri Chowk, New Delhi
12. MoRTH (2013). Specifications for Road and Bridge Works, Indian Roads Congress, New Delhi, India.
13. MoRD (2014). Specifications for Rural Roads, Indian Roads Congress, New Delhi.
14. CSIR-CRRI Report (2014). Quality Assurance of Construction of Eastern Approach Embankment & Guide bund of a Signature Bridge, Delhi Tourism & Transport Development Corporation, New Delhi.
15. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.

16. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi.
17. Rao, G.V. (2020). Use of Industrial Bulk Waste Material in Indian Infrastructure Development. A Critical Appraisal, Indian Journal of Geosynthetics and Ground Improvement, Vol 9, 3-6.

Copper Slag

18. OECD (1977). Use of Waste Materials and Byproducts in Road Construction, Organization for Economic Co-operation and Development (OECD), Paris, France, 68-69.
19. Das, B.M., Tarquin, A.J. and Jones, A.Q. (1993). Geotechnical Properties of Copper Slag, Transportation Research Record No. 941, National Research Board, Washington, DC, USA.
20. Havanagi, V.G., Prasad, P.S, Guruvittal, U.K. and Mathur, S. (2006). Feasibility of Utilization of Copper Slag-Fly ash-Soil Mixes for Road Construction. Highway Research Bulletin, Indian Roads Congress. No.75, pp 59-75.
21. Havanagi, V.G., Mathur, S., Prasad P.S. and Kamaraj, C.(2007). Feasibility of Copper Slag-Fly ash-Soil Mix as a Road Construction Material, Journal of Transportation Research Board, Vol 2. No.1989, 13-20.
22. Havanagi, V.G., Sinha, A.K., Prasad, P.S, Sitaramanjaneyulu and Mathur, S. (2009). Copper Slag as an Alternative Material for Road Construction. Proceeding of 24th International Conference on Solid Waste Technology and Management, 15th-18th March, Philadelphia, USA, 133-44.
23. Havanagi, V.G., Sinha, A.K., Arora, V.K. and Mathur, S. (2012). Design and Stability Analysis of Copper Slag Embankment, Journal of Indian Highways, vol. 40(10), 17-23
24. MoRTH (2013). Specifications for Road and Bridge Works, Indian Roads Congress, New Delhi, India.
25. MoRD (2014). Specifications for Rural Roads, Indian Roads Congress, New Delhi
26. Havanagi, V.G., Sinha, A.K. and Ranjan, A. (2015). Fine Copper Slag as an Alternative Marginal Material for Road Construction, Journal of Indian Highways, IRC, Vol. 44(1), pp 25-33.
27. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
28. IRC:SP:121 (2018). Guidelines for Use of Iron, Steel and Copper Slag in Construction of Rural Roads, Indian Roads Congress, New Delhi.
29. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi.

Jarofix

30. USEPA Method - 1311(1992). The Toxicity Characteristic Leaching Procedure (TCLP) Test, Published by the United States Environmental Protection Agency (USEPA), USA.
31. Sinha, A.K., Havanagi, V.G., Arora, V.K., Ranjan, A. and Mathur, S. (2012). Recycling Jarofix Waste as a Construction Material for Embankment and Subgrade, *International Journal of Solid Waste Technology and Management*, vol. 38(3), pp 169-181.
32. Sinha, A.K., Havanagi, V.G., Arora, V. K., Ranjan, A. and Mathur, S. (2013). Characterization of Jarofix Waste Material for the Construction of a Road, *Journal of Highway Research Board, Indian Road Congress*, Vol. 6 (2), pp 35-43.
33. MoRTH (2013). Specifications for Road and Bridge Works, Ministry of Road and Highway Transport, New Delhi, India.
34. MoRD (2014). Specifications for Rural Roads, Indian Roads Congress, New Delhi
35. Anu, Raj, Beena, K.S., Santhosh, G., & Santhosh, K.N. (2014). Geoenvironmental Characteristics of Jarofix Mixed Soil. *Proceedings of International Conference on Energy, Environment, Materials and Safety*, Kochi, India pp. 293–298.
36. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
37. Sinha, A.K., Havanagi, V.G. and Shahu, J.T. (2018). Characterization of Jarofix for Usage in Geotechnical Projects, *Proceedings of the Institution of Civil Engineers – Geotechnical Engineering*, 171(5), pp 439–450.
38. Sinha, A.K., Havanagi, V.G. and Shahu, J.T. (2019). Stabilised Jarofix Waste Material for Road Construction, *International Journal of Pavement Engineering*, DOI 10.1080/10298436.2019.1652299.
39. Sinha, A.K., Havanagi, V.G. and Shahu, J.T. (2019). Construction and Performance of Jarofix Waste Material Embankment, *Proceedings of the Institution of Civil Engineers – Construction Materials*. <https://doi.org/10.1680/jcoma.18.00003>.
40. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi
41. Beena, K.S., Santhosh, G. (2020). Transport Geotechnical Properties of Lateritic Soil Stabilized with Jarofix and Lime, *Journal of Environment Development and Sustainability*, <https://doi.org/10.1007/s10668-020-00641-0>.

Phosphogypsum

42. Tamj, T., Roger, K.S., Marty, E.T., Willis, T.J. and James, T.H. (1984). Use of By-Product Phosphogypsum in Road Construction, *Transportation Research Record* 1345, pp 28-35.
43. The Report, Institute of Phosphate Research (1989). Phosphogypsum for Secondary Road Construction, University of Miami, Florida.

44. Staineslaw, F., Barbara, W., Bozena, W., and Jolanta, M. (2011). Use of Phosphogypsum in Road Construction, Polish Journal of Geotechnical Technology, 13, 2, pp18-22.
45. MoRTH (2013). Specifications for Road and Bridge Works, Indian Roads Congress, New Delhi, India.
46. MoRD (2014). Specifications for Rural Roads, Indian Roads Congress, New Delhi
47. CPCB Report (2014). Guidelines for Management, Handling, Utilization and Disposal of Phosphogypsum Generated from Phosphoric Acid Plant, MoEF&CC, New Delhi.
48. Dutta, Rakesh Kumar and Kumar, Vaibhav, (2016). Suitability of Fly ash-Lime-Phosphogypsum for Road Pavements, Periodica Polytechnic Civil Engineering, 60 (3), pp 455-469.
49. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
50. Havanagi, V.G., Sinha, A.K. and Parvathi, G.S. (2018). Characterization of Phosphogypsum Waste for Road Construction, Proceedings of Indian Geotechnical Conference, Bangalore, (Paper ID: TH-09-009).
51. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi

Marble Dust

52. Zorluer, I. & Taspolat, L.T. (2009). Reuse of Waste Marble Dust in the Landfill Layer, First International Symposium on Sustainable Development. Sarajevo, Bosnia and Herzegovina. pp 301-305.
53. Misra, A.K., Mathur, R., Rao, Y.V., Singh, A.P., and Goel, P. (2010). The New Technology of Marble Slurry Waste Utilization in Roads. Journal of Scientific & Industrial Research, Vol. 69, pp 67-72.
54. MoRTH (2013). Specifications for Road and Bridge Works, Indian Roads Congress, New Delhi, India.
55. MoRD (2014). Specifications for Rural Roads, Indian Roads Congress, New Delhi
56. Altug SAYGILI (2015). Use of Waste Marble Dust for Stabilization of Clayey Soil, Materials Science, 21(4): 601–606.
57. Chen, James A. and Uloko, Josiah O. (2017). Comparative Study of Effect of Waste Ceramic and Marble Dusts on Geotechnical Properties of Expansive Soil, 22 (Bund. 13):5075-5084.
58. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi

Other Potential Waste Materials

Foundry Sand

59. Fox, P.J. and Mast, D.G. (1998). Geotechnical Performance of Highway Embankment Constructed using Waste Foundry Sand. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana. DOI 10.5703/1288284313231.
60. Kirk, P.B. (1998). Field Demonstration of Highway Embankment Constructed using Waste Foundry Sand. PhD. Dissertation, Purdue University, West Lafayette.
61. MoRTH (2013). Specifications for Road and Bridge Works, Indian Roads Congress, New Delhi, India.
62. MoRD (2014) Specifications for Rural Roads, Indian Roads Congress, New Delhi.
63. Kumar, Amrendra, Sharma, R.K. and Singh, Babita (2014). Compaction and Sub-grade Characteristics of Clayey Soil Mixed with Foundry Sand and Fly Ash and Tile Waste. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X PP 01-05.
64. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi
65. Sinha, A.K., Vinoth, M., Shanker, S. Ravi and Havanagi, V.G. (2020). Characterisation of Foundry Sand Waste Material for Road Construction. Journal of New Building Materials & Construction World (NBM&CW), New Delhi, Vol. 25(9), pp 74 – 85

Granulated Blast Furnace Slag

66. CSIR-CRRI Report (1995). Use of Granulated Blast Furnace Slag in Road Works. Vishakhapatnam Steel Plant, Vishakhapatnam, Andhra Pradesh.
67. CSIR-CRRI Report (1997). Steel Plant By-Products in Road Works, Rourkela Steel Plant, Rourkela, Orisha.
68. Pathak, Ashish Kumar (2014). International, Journal of Engineering Research and Applications ISSN: 2248-9622, Vol. 4, Issue 5, pp.164-171.
69. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
70. Preetham, H.K., Nayak, S. (2019). Geotechnical Investigations on Marine Clay Stabilized Using Granulated Blast Furnace Slag and Cement, International Journal of Geosynthetic. and Ground Engineering. 5, 28.
71. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi

Red Mud

72. Jiang, Y. and Ning, P. (2003) Comprehensive Utilization of Red Mud from Alumina Plant. Environmental Science Technology, 26, pp. 40–44.

73. Gangadhara, Reddy N. and Hanumantha, Rao B. (2016). Evaluation of the Compaction Characteristics of Untreated and Treated Red Mud, Geo-Chicago Chicago, Illinois, U.S.
74. Parvathi, G.S. and Ghosh, A. (2016). Capacity Augmentation of Red Mud Pond using Industrial Waste, International Geotechnical Engineering Conference on Sustainability in Geotechnical Engineering Practices and Related Urban Issues, Mumbai, India.
75. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
76. Parvathi, G.S., Sinha, A.K., Havanagi, V.G., (2019). "Red Mud - Fly Ash Mix as an Embankment Fill Material", Indian Highways 47 (3), pp 20-25.
77. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi

Chrome Slag

78. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
79. Sinha, A.K., Havanagi, V.G. and Kanaujia, V.K. (2017). Chrome Slag in Embankment and Pavement Construction. Journal of Highway Research Board, Indian Roads Congress, Vol.8 (1), pp 45-54.
80. Bhushan, A., and Prasad, B. (2019). Application of Ferrochrome Slag as an Embankment and Pavement Material A Review, Journal of Building Construction, Vol.1, Issue 3, pp1-6.
81. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi

Municipal Solid Wastes

82. MoUD (2000). Status Report on Municipal Solid Waste Management, Central Pollution Control Board, New Delhi.
83. MoRTH (2013). Specifications for Road and Bridge Work, Indian Roads Congress, New Delhi, India.
84. MoEF&CC (2016). Management, Handling and Transboundary Movement, Ministry of Environment and Forest, Government of India.
85. IRC:121-2017. Guidelines for Use of Construction and Demolition Waste in Road Sector, Indian Roads Congress, New Delhi.
86. Havanagi, V.G., Sinha, A.K., Parvathi, G.S., and Chandra, S. (2017). Municipal Solid Waste in Road Embankment Construction - A Case Study, Journal of Indian Roads Congress, Vol. 78(2), pp 79-90.
87. Toolkit (2019). Toolkit for the Implementation of Solid Waste Management Rules, 2016. National Productivity Council, Delhi

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